Journal
of
The Franklin Institute

EDITOR, HOWARD McCLENAHAN, E.E., LITT.D., D.Sc., LL.D.
ASSISTANT EDITOR, ALFRED RIGLING

Associate Editors:

JOSEPH S. AMES, PH.D.
WILDER D. BANCROFT, PH.D.
E. J. BERG, SC.D.
BRIG.-GEN. JOHN J. CARTY, LL.D.
E. G. COKER, F.R.S.
ARTHUR L. DAY, SC.D.
A. S. EVE, F.R.S.
PAUL D. FOOTE, PH.D.
W. J. HUMPHREYS, PH.D.
A. E. KENNELLY, SC.D.
C. E. K. MEES, D.SC.
RALPH MODJESKI, D.ENG.
MAJ.-GEN. G. O. SQUIER, PH.D.
W. F. G. SWANN, D.SC.
D. W. TAYLOR, LL.D.
A. F. ZAHM, PH.D.
JOHN ZELENY, PH.D.

Committee on Publications:

G. H. CLAMER, CHAIRMAN
A. W. GOODSPEED
CLARENCE A. HALL
GEORGE A. HOADLEY
MALCOLM LLOYD, JR.

Vol. 214 **DECEMBER, 1932** No. 6

CONTENTS

Non-Unilateral Oscillations: Governor-Controlled Engine-Driven Generators. M. STONE 633

Propagation Tests and the Photography of the Disturbance Sent Out by the Explosion of Commercial Electric Detonators ..... D. B. GAWTHROP 647

Cosmic Rays—Theory and Experimentation ..... THOMAS H. JOHNSON 665

Elastic Properties of Various Materials and Their Effect on the Transmission of Vibrations ..... B. E. EISENHOUR AND F. G. TYZZER 691

A Direct Current Bushing Transformer ..... ALAN S. FITZGERALD 709

The Franklin Institute Eclipse Expedition ..... JAMES STOKLEY 735

Notes from the U. S. Bureau of Standards 747

The Franklin Institute Notes 753

Book Reviews 758

Publications Received 770

Current Topics 690, 708, 734, 771

Index to Volume 214 777

Entered at the Post Office at Lancaster, Pa., March 14, 1928, as second-class matter under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on July 3, 1919.

Published by

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

Prince and Lemon Streets, Lancaster, Penna., and

15 South Seventh Street, Philadelphia, Penna.

SIX DOLLARS PER YEAR (Foreign Postage Additional) **SINGLE NUMBERS, SIXTY CENTS**

Indexes to the semi-annual volumes of the JOURNAL are published with the June and December numbers. The contents are also indexed in *The Industrial Arts Index.*

A Complete Plant Under One Roof

PRINTING - BINDING - ELECTROTYPING

Printers of
Scientific and Technical Journals and Books
Theses and Dissertations
Works in Foreign Languages

Your Book, Journal or Thesis placed with us insures that the composition, proof-reading, electrotyping, presswork and binding, follow through in consecutive order in one plant—established fifty-five years ago—and under the supervision of one management.

LANCASTER PRESS, Inc.

Established 1877 LANCASTER, PA.

[*Printers of Journal of The Franklin Institute*]

McNICHOL PAVING & CONSTRUCTION CO.

GENERAL CONTRACTORS

1923 CHERRY STREET PHILADELPHIA, PA.

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 214 DECEMBER, 1932 No. 6

NON-UNILATERAL OSCILLATIONS.

GOVERNOR-CONTROLLED ENGINE-DRIVEN GENERATORS.

BY

M. STONE, B.S., M.S.,

Engineer-in-charge of Development, Power Engineering Department, Westinghouse Electric & Manufacturing Company.

The problem that has given rise to the present discussion has especial interest, because it is one of the infrequent examples of a non-unilateral system that has practical importance.

In order to explain this, let us state what is meant by a unilateral system. If we have a system of n-coupled mechanical linkages or electric circuits of the unilateral (usual) type, it is possible to write down the final solution in simplified determinantal form, and algebraic expansion of the determinant is directly obtained. In the case of the non-unilateral type, a similar determinantal solution can be written, with less particular relations between the elements of the determinant, so that the expanded solution is not so easily won.

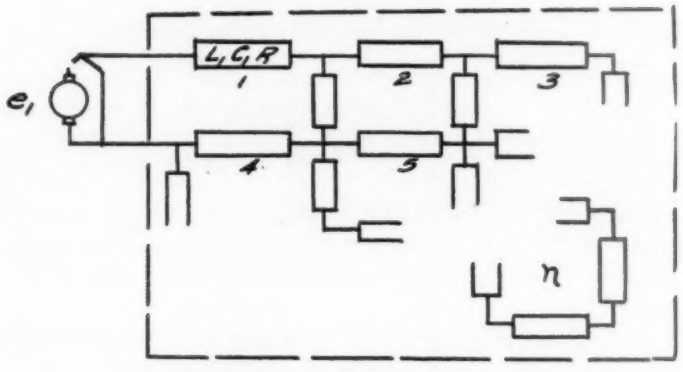
Take, for instance, the n-coupled electrical network shown in Fig. 1. Each system is thought to have inductance L, capacity C, and resistance R, and coupled together with every other system in the network, and in the most general way. The differential equations, whose determinantal solutions are obvious, for the variations in the charges q in each of the circuits, under an impressed potential e_1 in circuit 1, can be

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

written directly, as can be found in the books of Rayleigh [1] or Guillemin: [2]

$$\left.\begin{aligned} a_{11}q_1 + a_{12}q_2 + \cdots + a_{1n}q_n &= e_1 \\ a_{21}q_1 + a_{22}q_2 + \cdots + a_{2n}q_n &= 0 \\ \cdot \qquad\qquad\qquad\qquad\quad \cdot & \\ \cdot \qquad\qquad\qquad\qquad\quad \cdot & \\ \cdot \qquad\qquad\qquad\qquad\quad \cdot & \\ a_{n1}q_1 + a_{n2}q_2 + \cdots + a_{nn}q_n &= 0 \end{aligned}\right\} \tag{1}$$

FIG. 1.



N-degree of freedom coupled network.

where $q_k = \int i_k dt$, i_k being the current in the kth circuit. In (1), the general term $a_{ik}q_k$ is given by

$$a_{ik}q_k = \left(L_{ik}\frac{d^2}{dt^2} + R_{ik}\frac{d}{dt} + \frac{1}{C_{ik}} \right) q_k \tag{2}$$

and it is seen that a_{ik} is really an operator, defined as the bracket shows it. It is a known property of such circuits as have been described above, that since

$$\begin{aligned} L_{ik} &= L_{ki} \\ R_{ik} &= R_{ki} \\ C_{ik} &= C_{ki}, \end{aligned}$$

[1] Lord Rayleigh, "Theory of Sound," Vol. I, p. 104.
[2] E. A. Guillemin, "Communication Networks," J. Wiley & Sons, 1931.

it follows that $a_{ik} = a_{ki}$. This property labels the system "unilateral." The differential equations of all such systems can be thrown into the form (1)—their final solutions differing only in the values of the constants L, R, and C. Although a discussion of these systems is not the object of this paper, let us consider a little further the case of free oscillations of a 2-circuit net.

Free oscillations are denoted by the absence of any externally impressed potential, and may be obtained by subjecting the system to such a potential, and then switching over to eliminate the source—as provided for by the switch in Fig. 1. For the 2-circuit case, we should then have

$$\left.\begin{aligned} a_{11}q_1 + a_{12}q_2 &= 0 \\ a_{21}q_1 + a_{22}q_2 &= 0 \end{aligned}\right\}. \tag{3}$$

If we consider the particular solutions

$$\left.\begin{aligned} q_1 &= Q_1 e^{\beta t} \\ q_2 &= Q_2 e^{\beta t} \end{aligned}\right\} \tag{4}$$

and substitute in (3), we obtain

$$\left.\begin{aligned} \alpha_{11}Q_1 + \alpha_{12}Q_2 &= 0 \\ \alpha_{21}Q_1 + \alpha_{22}Q_2 &= 0 \end{aligned}\right\} \tag{5}$$

where the α's are now algebraic operators and are functions of β, having the form

$$\alpha_{ik} = L_{ik}\beta^2 + R_{ik}\beta + 1/C_{ik} \tag{6}$$

and it is still true that $\alpha_{ik} = \alpha_{ki}$. The values of α_{11}, α_{22}, and $\alpha_{12} = \alpha_{21}$, in (5) depend on how the two circuits are physically coupled together. For the sample cases, shown in Fig. 2, the α's are given on the right:

The solutions for the oscillation frequencies and damping exponents arise from substituting the various α's shown above in equation (5), and expanding the determinant of compatibility, to obtain

$$\begin{vmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{vmatrix} = 0$$

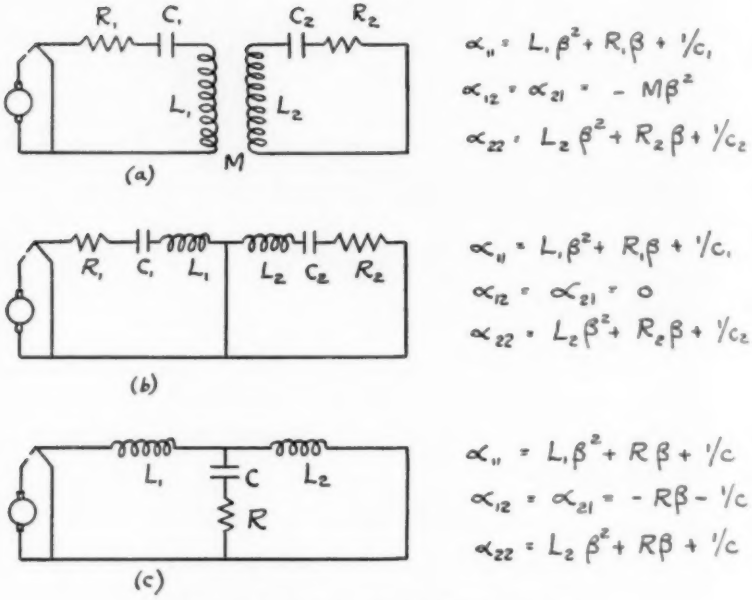
or

$$\alpha_{11}\alpha_{22} - \alpha_{12}^2 = 0. \tag{7}$$

This results, in general, in a quadratic in β^2, from which four values of β are obtained, pairs of 2 being conjugate complex, i.e.

$$\left.\begin{aligned}\beta_1 &= b_1 + ic_1\\ \beta_2 &= b_1 - ic_1\\ \beta_3 &= b_2 + ic_2\\ \beta_4 &= b_2 - ic_2\end{aligned}\right\}. \tag{8}$$

FIG. 2.


R, C, C2 R2
L, L2
M
(a)
$\alpha_{11} = L_1\beta^2 + R_1\beta + 1/C_1$
$\alpha_{12} = \alpha_{21} = -M\beta^2$
$\alpha_{22} = L_2\beta^2 + R_2\beta + 1/C_2$
R, C, L, L2 C2 R2
(b)
$\alpha_{11} = L_1\beta^2 + R_1\beta + 1/C_1$
$\alpha_{12} = \alpha_{21} = 0$
$\alpha_{22} = L_2\beta^2 + R_2\beta + 1/C_2$
L, C L2
R
(c)
$\alpha_{11} = L_1\beta^2 + R\beta + 1/C$
$\alpha_{12} = \alpha_{21} = -R\beta - 1/C$
$\alpha_{22} = L_2\beta^2 + R\beta + 1/C$

Various unilateral systems of two degrees of freedom.

The b's are the damping coefficients and the c's the frequencies, in the final solution of the form

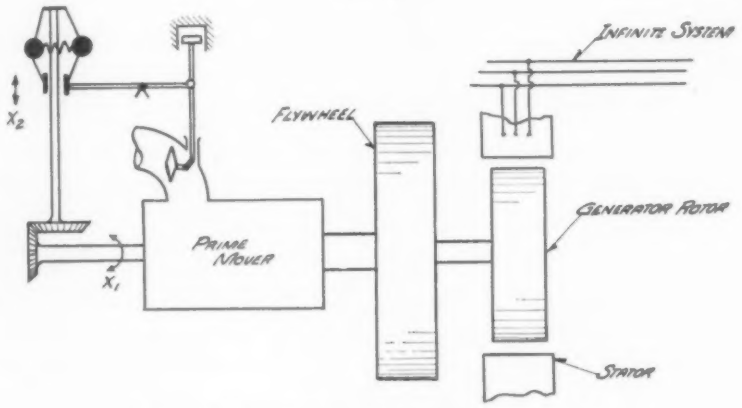
$$q_1 = Q_1'e^{b_1t}\sin(c_1t + \epsilon_1) + Q_1''e^{b_2t}\sin(c_2t + \epsilon_2). \tag{9}$$

The Q's and ϵ's in (9) are determined by the initial conditions alone, and are not indicative of the fundamental character of the oscillations. The b's are always *negative or zero* for unilateral systems—and the c's *positive or zero*. The general statement may be made that all electric circuits involving

coupling of the inductance, capacity, or resistance type fall in the class of unilateral systems.

The case of non-unilateral oscillations that has occasioned the present communication is that of direct-governed prime movers coupled to synchronous generators running in parallel or tied to an infinite electrical network. A schematic diagram of the latter is shown in Fig. 3:

FIG. 3.



Schematic diagram of governor-generator interconnection.

Since the generator above shown is running in parallel with a network, there exists synchronizing torque tending to hold the rotor in its synchronous position, damping torque supplied by the eddy currents flowing in pole faces, solid parts, damper winding, etc., and an inertia reaction, contributed by the generator rotor, flywheel, and prime mover parts. The differential equation of free oscillation of the ungoverned generator system is written as

$$m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 = 0, \qquad (10)$$

where

m_1 = mass moment of inertia of generator + flywheel + engine.

x_1 = angular displacement from synchronous position.

c_1 = specific damping torque.

k_1 = specific synchronizing torque.

The governor itself comprises an oscillatory system,[3] the differential equation of free oscillation of which, can be written

$$m_2\ddot{x}_2 + c_2\dot{x}_2 + k_2x_2 = 0, \tag{11}$$

where

m_2 = equivalent mass of the governor referred to sleeve motion.

x_2 = linear displacement of governor sleeve from equilibrium position.

c_2 = specific damping force, supplied by dash pot, etc.

k_2 = restoring force, supplied by spring, or the like.

With the governor and prime mover properly interconnected, the equation of free coupled oscillation becomes[4]

$$\left.\begin{aligned} m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 &= kx_2 \\ m_2\ddot{x}_2 + c_2\dot{x}_2 + k_2x_2 &= -c\dot{x}_1 \end{aligned}\right\} \tag{12}$$

where c and k are constants that determine quite entirely the character of the coupled oscillations. Admitting, now, the particular solution:

$$\left.\begin{aligned} x_1 &= X_1e^{\beta t} \\ x_2 &= X_2e^{\beta t} \end{aligned}\right\}, \tag{13}$$

equations (13) substituted in (12) yield

$$\left.\begin{aligned} X_1(m_1\beta^2 + c_1\beta + k_1) + X_2(-k) &= 0 \\ X_1(c\beta) + X_2(m_2\beta^2 + c_2\beta + k_2) &= 0 \end{aligned}\right\} \tag{14}$$

from which we see that our α's are

$$\begin{aligned} \alpha_{11} &= m_1\beta^2 + c_1\beta + k_1 \\ \alpha_{12} &= -k \\ \alpha_{21} &= c\beta \\ \alpha_{22} &= m_2\beta^2 + c_2\beta + k_2. \end{aligned}$$

Here $\alpha_{12} \neq \alpha_{21}$.

The character of the motion is defined by the compatibility relation

$$\alpha_{11}\alpha_{22} - \alpha_{12}\alpha_{21} = 0, \tag{15}$$

[3] See M. Tolle, "Die Regelung der Kraftmaschinen," J. Springer, 1921.

[4] M. Stone, "Parallel Operation of A.C. Generators," A.I.E.E., Mid-Winter Meeting, 1932–33.

which is somewhat different, now, from (7), because of the absence of the unilateral property. The algebraic complexity to solve such equations of type (15) is no greater than for type (7), however. The expansion of (15) yields

$$\beta^4 + \beta^3\left[\frac{c_1}{m_1} + \frac{c_2}{m_2}\right] + \beta^2\left[\frac{k_1}{m_1} + \frac{k_2}{m_2} + \frac{c_1}{m_1}\cdot\frac{c_2}{m_2}\right] + \beta\left[\frac{k_1}{m_1}\cdot\frac{c_2}{m_2} + \frac{k_2}{m_2}\cdot\frac{c_1}{m_1} + \frac{ck}{m_1m_2}\right] + \left[\frac{k_1}{m_1}\cdot\frac{k_2}{m_2}\right] = 0. \tag{16}$$

This 4th degree algebraic equation gives us four solutions for β, similar to those in (8):

$$\left.\begin{aligned}\beta_1 &= p' + iq'\\ \beta_2 &= p' - iq'\\ \beta_3 &= r' + is'\\ \beta_4 &= r' - is'\end{aligned}\right\}, \tag{17}$$

which transform the solution, made up of terms like (13), to a form similar to that of (9). Of paramount concern to us are the values of p' and r', since they alone indicate the stability, or the instability, of the governing under oscillations set up by sudden changes in generator load.

Now by writing down

$$(\beta - \beta_1)(\beta - \beta_2)(\beta - \beta_3)(\beta - \beta_4) = 0 \tag{18}$$

and expanding, and comparing with (16), and then introducing the values of $\beta_1 \cdots \beta_4$ as shown in (17), we obtain the relations:

$$p' + r' = -\tfrac{1}{2}\left(\frac{c_1}{m_1} + \frac{c_2}{m_2}\right)$$

$$p'^2 + q'^2 + r'^2 + s'^2 + 4p'r' = \frac{k_1}{m_1} + \frac{k_2}{m_2} + \frac{c_1}{m_1}\cdot\frac{c_2}{m_2}$$

$$r'(p'^2 + q'^2) + p'(r'^2 + s'^2) = -\tfrac{1}{2}\left(\frac{k_1}{m_1}\cdot\frac{c_2}{m_2} + \frac{k_2}{m_2}\cdot\frac{c_1}{m_1} + \frac{ck}{m_1m_2}\right)$$

$$(p'^2 + q'^2)(r'^2 + s'^2) = \frac{k_1}{m_1}\cdot\frac{k_2}{m_2}.$$

Now by recognizing, however, that

$$p = -\frac{c_1}{2m_1}, \qquad r = -\frac{c_2}{2m_2}, \qquad p^2 + q^2 = \frac{k_1}{m_1} = w_1^2$$

and

$$r^2 + s^2 = \frac{k_2}{m_2} = w_2^2;$$

and writing likewise $p'^2 + q'^2 = w_1'^2$, and $r'^2 + s'^2 = w_2'^2$, we have finally

$$\left.\begin{aligned} p' + r' &= p + r \\ w_1'^2 + w_2'^2 + 4p'r' &= w_1^2 + w_2^2 + 4pr \\ r'w_1'^2 + p'w_2'^2 &= rw_1^2 + pw_2^2 - \gamma \\ w_1'^2 \cdot w_2'^2 &= w_1^2 \cdot w_2^2 \end{aligned}\right\}, \tag{19}$$

where

$$\gamma = \frac{ck}{2m_1m_2} = \frac{w_2^2}{2\delta\tau},$$

as is shown in the paper referred to earlier.[4] Here

δ = regulation of governor (about 5%, $\delta = 0.05$).
τ = time to bring total generator system to full speed from standstill under full load torque (in seconds).

The value γ represents the efficacy of governing and must be called the "characteristic constant" of the combined generator and governor system—its value is always positive. It is due to this last fact that p' and r' may be zero or positive, as well as negative—while for unilateral systems, p' and r' are never positive, and only zero in the trivial case of no dissipative terms in the system.

Equations (19) are a remarkably symmetrical set of equations, the solution of which we are immediately concerned with. We have here 4 non-linear algebraic equations in the 4 unknowns p', q', r', and s', and are put to considerable complexity to solve them. This can be done, however, with the use of the auxiliary cubic. Since we are primarily interested, however, in the stability relations in our system, let us take advantage of our physical concepts to simplify the solution. Referring to (19), by extracting the square root of (19*d*), and adding 2 times the result to (19*b*), we obtain

$$(w_1' + w_2')^2 + 4p'r' = (w_1 + w_2)^2 + 4pr. \tag{20}$$

Repeating, this time subtracting,

$$(w_1' - w_2')^2 + 4p'r' = (w_1 - w_2)^2 + 4pr. \tag{21}$$

Now, equation (20) may be written as

$$w_1' + w_2' = \sqrt{(w_1 + w_2)^2 + 4(pr - p'r')} \tag{22}$$

and likewise (21), as

$$w_1' - w_2' = \sqrt{(w_1 - w_2)^2 + 4(pr - p'r')}. \tag{23}$$

The positive square root is always meant, and it is arbitrarily assumed that $w_1' > w_2'$. From (22) and (23), we get expressions for the w's, by elimination:

$$\begin{aligned} w_1' &= \tfrac{1}{2}\sqrt{(w_1 + w_2)^2 + 4(pr - p'r')} \\ &\qquad + \tfrac{1}{2}\sqrt{(w_1 - w_2)^2 + 4(pr - p'r')} \\ w_2' &= \tfrac{1}{2}\sqrt{(w_1 + w_2)^2 + 4(pr - p'r')} \\ &\qquad - \tfrac{1}{2}\sqrt{(w_1 - w_2)^2 + 4(pr - p'r')}. \end{aligned} \tag{24}$$

Now, by multiplying (19a) by $w_1'^2$, and eliminating between the result and (19c), we get for p':

$$p' = \frac{(p + r)w_1'^2 - (rw_1^2 + pw_2^2 - \gamma)}{w_1'^2 - w_2'^2}. \tag{25}$$

Now, as was discussed earlier, stability of governing is indicated by having both p' and $r' < 0$. Now, from an examination of (19a), it is seen that if there were no damping in either the governor or generator systems, i.e. $p = r = 0$, then it would be impossible to have stable operation, since p' would equal $-r'$, which $\neq 0$, because of (19c). We thus observe that it is imperative to have damping in either the generator or the governor system (not necessarily both) to begin with. It is more usual to provide this damping in the governor system, by introduction of dash pots or the like. In general, however, with both p and $r \neq 0$ (both being actually negative quantities), we must follow the force of the argument presented by considering the border-line case, $p' = 0$. For $p' = 0$, r' must be negative, from relation

(19*a*), since both p and r are negative; so that whereas the amplitudes of one type of oscillation would continue undiminished, the other would die away—and the condition would be called stable. Now, for p' slightly < 0, r' would still remain < 0, and stability in its real sense would be established.

We are interested then in determining what conditions are necessary to make $p' = 0$. By placing $p' = 0$ in (22) ··· (24), and substituting the values of w_1' and w_2' thus obtained in (25), the *criterion of stability* becomes

$$0 > \frac{w_2^2\left(\frac{1}{2\delta\tau} - p\right) - rw_1^2 + \frac{p+r}{2}\left\{w_1^2 + w_2^2 + 4pr + \sqrt{(w_1^2 - w_2^2)^2 + 8pr(w_1^2 + w_2^2) + 16p^2r^2}\right\}}{\sqrt{(w_1^2 - w_2^2)^2 + 8pr(w_1^2 + w_2^2) + 16p^2r^2}}. \tag{26}$$

From an examination of the relative magnitudes, that occur practically, in (26), which are roughly given by

$$\begin{aligned} w_1 &\approx 20 \text{ rad./sec.} \\ \delta &\approx .03 \\ \tau &\approx 10 \text{ sec.} \\ p \approx r &\approx -1.\text{c}, \end{aligned}$$

equation (26) can be simplified very much. Calling the ratio $w_2/w_1 = \rho$, we thus obtain for $\rho > 1$,

$$\left.\begin{aligned} &\frac{\left(\frac{1}{2\delta\tau} + r\right)\rho^2 - r}{\rho^2 - 1} < 0. \\ &\text{for } \rho < 1 \\ &\frac{\left(\frac{1}{2\delta\tau} - p\right)\rho^2 + p}{1 - \rho^2} < 0 \\ &\text{for } \rho = 1 \\ &\frac{w}{8\delta\tau\sqrt{pr}} + \frac{p+r}{2} < 0 \end{aligned}\right\} \tag{27}$$

as the criteria of stability, in the ranges specified. From (27), it is clear that

(1) if $w_2 > w_1$, large governor damping is necessary to produce stability.
(2) If $w_2 < w_1$, a damper winding is necessary.
(3) If isochronism exists, damping must exist in both the governor and the generator systems, and to a much larger degree than in either (1) or (2).

In order to illustrate the significance of the stability relations (27), call the left side of the equations $\phi(\rho)$, where δ and τ are held constant at values 0.03 and 10 sec. respectively—w in (27c) is evaluated at 20 rad./sec. By plotting $\phi(\rho)$ vs. ρ for values of p and r ranging from 0 to -3.0, the stability ranges shown in the accompanying curves, Fig. 4, are obtained, i.e. for

$$\phi(\rho) > 0, \text{ instability,}$$
$$\phi(\rho) < 0, \text{ stability.}$$

The nature of the practical results—regarding the quantitative effect of damping in one system, on general coupled oscillations—was such that the author looked for means of confirmation, other than experimenting with large power units, operating under various conditions of paralleling. In considering what types of electrical circuits were analogous to the generator-governor oscillating system, it is immediately realized that since our problem is one of non-unilateral oscillations, that it is impossible to create an analogy through inductance, capacity, or resistance coupling, or combinations thereof. The problem is one of having the derivative of variable$_1$ controlling variable$_2$, but in return, variable$_2$ controls variable$_1$ directly—see equations (12). This naturally led to a consideration of oscillating circuits with vacuum tubes, and the most desirable arrangement, here shown, came out of a discussion with Dr. J. Slepian.

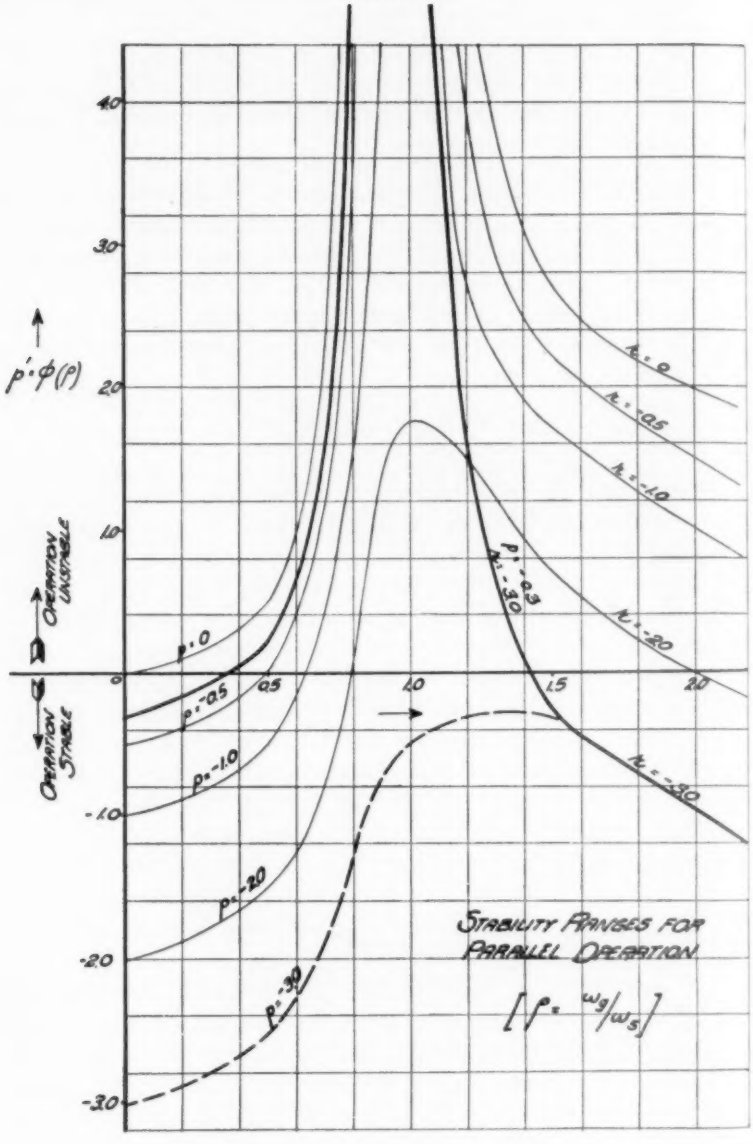
The analogy is disclosed by considering the differential equations of potential interchange in each circuit. In circuit I, the instantaneous potential distribution is given by

$$L_1\ddot{q}_1 + R_1\dot{q}_1 + \frac{1}{C_1}q_1 + e_{p_1} = 0, \tag{28}$$

where

q_1 = charge on condenser$_1$,
e_{p_1} = potential across tube$_1$.

FIG. 4.


40
30
20
10
0
-10
-20
-30
p'·φ(p)
OPERATION UNSTABLE
OPERATION STABLE
.5
1.0
1.5
2.0
p=0
p=-.5
p=-1.0
p=-2.0
p=-3.0
k=0
k=-.5
k=-1.0
k=-2.0
k=-3.0
k=-.3
STABILITY RANGES FOR PARALLEL OPERATION
[f = ω3/ω5]

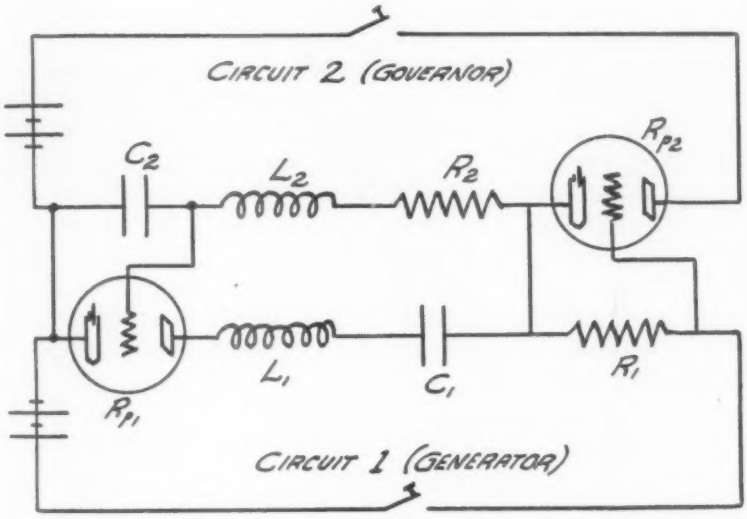
Similarly, for circuit II, we obtain

$$L_2\ddot{q}_2 + R_2\dot{q}_2 + \frac{1}{C_2}q_2 + e_{p_2} = 0. \tag{29}$$

Now e_{p_1} and e_{p_2}, by virtue of the electrical connections involving both circuits, are given by

$$\left.\begin{aligned} e_{p_1} &= R_{p_1}\dot{q}_1 - \frac{\mu_1}{C_2}q_2 \\ e_{p_2} &= R_{p_2}\dot{q}_2 + \mu_2 R_1\dot{q}_1 \end{aligned}\right\}. \tag{30}$$

FIG. 5.



Oscillating tube circuits analogous to governor-controlled engine-driven generators in parallel.

Here R_{p_1} and R_{p_2} are the plate circuit resistances in the two valves, and μ_1 and μ_2 the voltage amplification factors of the two tubes—it is seen that in one case, a negative grid bias, and in the other a positive grid bias is necessary. Introducing (30) in (28) and (29), we get

$$\left.\begin{aligned} L_1\ddot{q}_1 + (R_1 + R_{p_1})\dot{q}_1 + \frac{1}{C_1}q_1 &= \frac{\mu_1}{C_2}q_2 \\ L_2\ddot{q}_2 + (R_2 + R_{p_2})\dot{q}_2 + \frac{1}{C_2}q_2 &= -\mu_2 R_1\dot{q}_1 \end{aligned}\right\} \tag{31}$$

By comparing (31) with (12), we see that a complete and exact analogy has been disclosed. Thus by setting up experimentally, on a laboratory table, the tube circuits shown in Fig. 5, the complete sequence of events in governor-controlled engine-driven generators operating in parallel, may be studied.

SUMMARY.

This paper has shown the nature of the oscillatory phenomena involved in the parallel operation of A.C. generators driven by governor-controlled prime movers to be either stable or unstable, depending on the magnitude of the various electrical and mechanical quantities in the system. Further, such systems are non-unilateral coupled systems, and thus classify themselves as systems capable of self-induced vibration, i.e. systems which, when once displaced from equilibrium, will oscillate with increasing amplitude. An analogous electric circuit, which permits of easy experimental solution of the more cumbersome actual case, was disclosed, involving vacuum tubes—no analogue being possible with ordinary inductance, capacity, or resistance coupling, because these latter always form unilateral systems, and never display instability. Further investigations concerning these phenomena in allied circumstances will form the basis for future publication.

PROPAGATION TESTS AND THE PHOTOGRAPHY OF THE DISTURBANCE SENT OUT BY THE EXPLOSION OF COMMERCIAL ELECTRIC DETONATORS.[1]

BY

D. B. GAWTHROP.[2]

The development by manufacturers of new types of detonators used to fire explosives has established, in some cases, the use of a product which is totally different in chemical composition from the more usual type of detonator. Comparative tests showing the physical results obtained when these detonators are fired are of importance in determining the reliability of the detonators as an initiator of an explosion. In blasting operations which are carried out in coal or metal mines, it is essential that initiation of explosion shall be certain and that the explosive shall develop its full power. Otherwise a charge of explosive may be ineffective or may misfire.

A compressed mixture of mercury fulminate and potassium chlorate has been the preferred material for the initiating composition in a detonator. Other substances have been sought to replace this composition, mainly on account of its high cost, with the result that compounds such as tetryl, lead azide, picric acid, nitromannite, lead styphnate, and others are used in commercial detonators, which entirely or in part replace mercury fulminate.

This paper presents a photographic study of the disturbance sent out into the air when detonators of different chemical compositions are fired, and what the effects of such disturbances are in producing detonation in a charge of explosive located at a distance from the detonator. By identifying and noting the speeds of the components of the disturbance, it was believed that information could be ob-

[1] Published by permission of the Director, U. S. Bureau of Mines.

[2] Assistant explosives engineer, U. S. Bureau of Mines, Pittsburgh Experiment Station, Pittsburgh, Pa.

tained as to the method by which detonation is transferred from a detonator to a distant charge of explosive. In addition, measurement of the distances to which detonation is propagated over an air gap to a charge of explosive should furnish comparable data concerning the values of these detonators as initiators.

The ability of detonators to initiate detonation in a charge of explosive located at a distance from the detonator, is of particular interest when a detonator shield is used in firing the explosive. In this method [3, 4] the detonator is inclosed in a plug of wood or other inert material in such a way that its base only is in approximate contact with the explosive to be fired. In contrast with the usual method of embedding the detonator directly in a cartridge of explosive, the use of a shielded detonator or "dummy primer," as this shield has been called, often results in the production of an air gap by which the detonator is separated from the charge of explosive. In Fig. 1*a* is shown a type of detonator shield which does not permit a direct contact of the detonator and explosive.

THEORY OF DETONATION.

A concept of the mechanics of detonation is that the explosive is affected by a sudden impulse which develops high pressures and causes an enormous local rise in temperature in an extremely short time. Such a belief has been expressed by Berthelot,[5] Threlfall,[6] Wöhler,[7] and more recently by Grotta,[8] and is generally accepted. Inasmuch as the direct measurement of instantaneous pressures and temperatures developed by detonating compounds offers considerable difficulty, other methods have been employed to measure the efficiency of detonators.

The action of detonating compounds may be separated into two distinct factors. The velocity of the chemical

[3] Manning, R. I. C., and Soule, T., *Explosives Eng.*, **9**, p. 209, 1931.

[4] Richardson, R. G., *Trans. Inst. of Min. Eng.*, **80**, p. 358, 1931.

[5] Berthelot, M., "Explosives and Their Power," pp. 469–70, English translation John Murray, London, 1892.

[6] Threlfall, R., *Phil. Mag.*, **21**, p. 164, 1886.

[7] Wöhler, L., *Zeits. angew Chemie*, **24**, pp. 1111, 2089, 1911.

[8] Grotta, B., *Chem. and Met. Eng.*, **26**, p. 1126, 1922.

reaction, or its acceleration within the explosive, constitutes what is styled the "quickness" of the explosive.[7] The quickness of an explosive is measured by the lead plate test [8] which is not affected to any material extent by variations in the weights of charges. A measure of the "strength" or the total volume of gases from the explosive, is found in the internal expansion of a small Trauzl block [9] or in the amount of sand crushed in the sand test.[10] "Strength" and "quickness" as applied to detonators cannot be entirely separated since neither one alone can be counted upon to measure the functions of a good detonator, but the "quickness" is considered more important than the strength.

SHOCK WAVES AND OTHER DISTURBANCES.

There are present in the air, following the explosion of a detonator, the shock wave, gaseous products of detonation, and flying debris. The shock wave has been shown to be a discontinuous wave motion advancing in the air ahead of any forward movement of the gases liberated by the explosive. This wave advances at a speed greater than the speed of sound in air, but as it expands spherically its forward velocity is lessened. Flying bits of debris, which are chiefly fragments of the copper shell, maintain their velocity due to their inertia and soon overtake the shock wave. Instantaneous photographs and velocity measurements of these disturbances sent out by the explosion of a detonator were obtained by means of the Schlieren method of photography.

SCHLIEREN PHOTOGRAPHY.

This method of photography was originated by Topler [11] in 1867, and depends for its operation upon the refraction of a beam of light at a surface where there is a distinct change in density of the atmosphere. A shock wave which is normally invisible may be photographed with a Schlieren optical arrangement since a sharp difference in density, due to pressure, exists between the wave front and the undisturbed air in which it is advancing.

---

[9] Culver, E., "High Explosives," p. 552, Van Nostrand, New York, 1918.
[10] Storm, C. G. and Cope, W. C., Bureau of Mines Tech. Paper 125, 1916.
[11] Topler, A., *Ann. der Phys. u. Chem.*, 131, p. 33, 1867.

A description of the Schlieren apparatus used for taking instantaneous photographs [12] and moving film records,[13] has been given in previous publications by the author. Payman [14] describes the method and furnishes a comprehensive survey of the literature.

Electric detonators cannot be fired directly in the field of view of the Schlieren camera without causing damage to the apparatus from flying fragments of the metal shell of the detonator. For this reason the detonators were screened from the apparatus by a short length of pipe 15.0 cm. in diameter. A pipe cap having a hole in its center 3.8 cm. in diameter was screwed on to the end of the pipe. The disturbance from an exploding detonator was sent out through the hole in the pipe cap into the field of view of the camera.

INSTANTANEOUS PHOTOGRAPHS OF EXPLOSION OF DETONATORS.

Figure 2 shows diagrammatically the placement of the detonator. In Fig. 3 are three photographs of the disturbance sent out by each of four types of detonators. The first photograph in each group was taken soon after the explosion was initiated, with the axial line of the camera in a line intersecting at right angles the plane of Fig. 2 at the center of first position. The second photograph was taken later from the same position when the shock wave had passed the center of the field of view of the camera. The camera was then moved 30 cm. farther away from the site of the explosion so as to correspond to third position. The third photograph is taken at a time which corresponds closely to that of the second photograph, each photograph representing a separate trial, which was fired under the same condition.

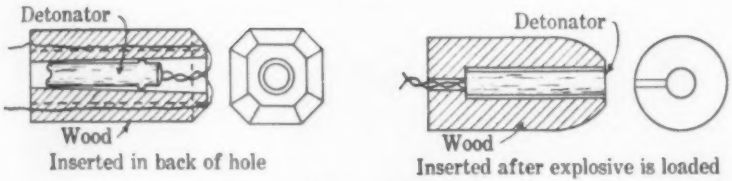
In photographs taken in this manner, fragments of the detonator shell are shown in advance of the shock wave and gaseous products of detonation. Each particle of the metal shell has a velocity higher than the velocity of sound in air and produces a conical wave identical to the wave sent out

[12] Gawthrop, D. B., "Review of Scientific Ins.," **2**, p. 522, 1931.

[13] Gawthrop, D. B., Shepherd, W. C. F. and Perrott, G. St. J., J. FRANK. INST., **211**, p. 67, 1931.

[14] Payman, W. and Robinson, H., Safety in Mines Research Board, Paper No. 18, Part I, 1926.

FIG. 1.



Two types of detonator shields in use.

FIG. 2.

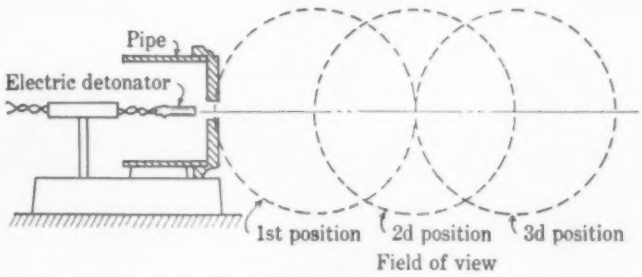


Diagram showing the position of the electric detonator for the photography of its explosion.

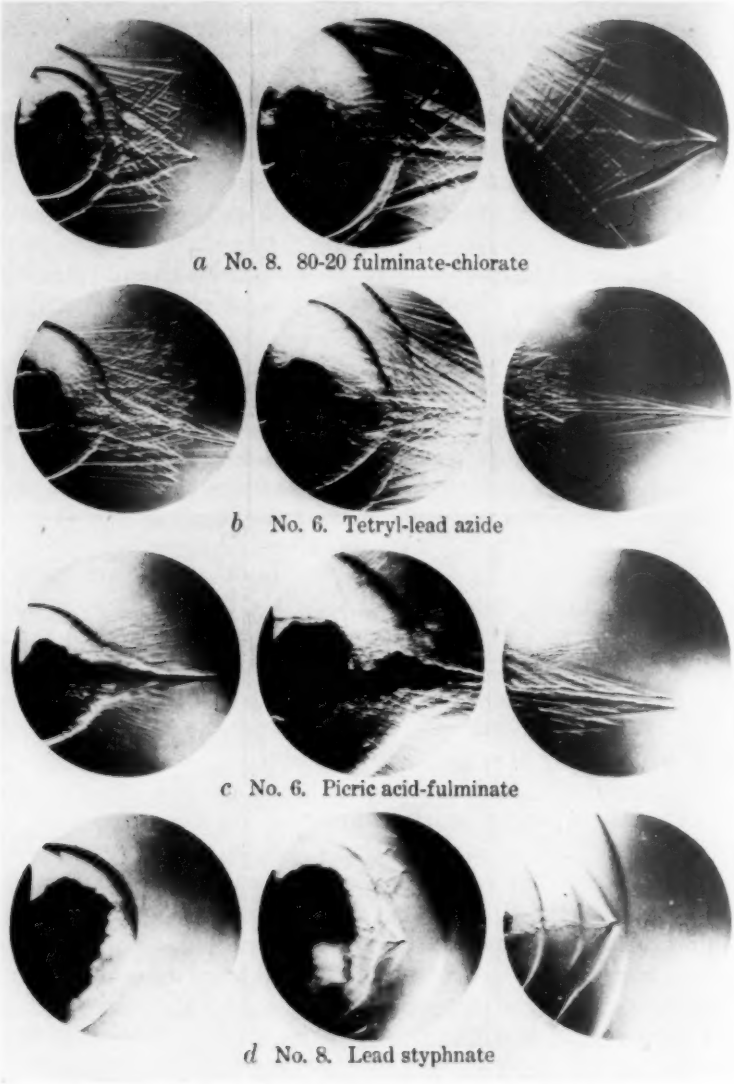
by a bullet in flight.[15] Usually two shock waves are visible in the photograph, one sent out directly by the explosion of the detonator, and a second one which is possibly the same wave reflected from the back of the detonator. The shock wave, expanding spherically with diminishing velocity of translation, is followed by opaque products of detonation which are moving at a much lower rate.

The important factors in these photographs are the size and velocity of the particles sent out by the explosion of the detonator. The size of the particles may be roughly determined from the photographs since each particle is made visible by its attendant conical wave even if the particle is so small that it registers in the photograph as a point. The velocity of any particle can be calculated from a measurement of the angle between the conical wave and the direction of movement of the particle.

$$v = k \operatorname{cosec} \alpha,$$

[15] Quayle, P., J. FRANK. INST., 193, p. 627, 1922.

FIG. 3.



Instantaneous photographs of the discharge sent out by electric detonators.

where k is the velocity of sound in air at the temperature of the experiment and α is the angle mentioned. According to Cranz [16] the accuracy of this method for measuring the velocity of a bullet in flight compares favorably with that of a chronograph.

The fragmentation of a No. 8 80–20 mercury fulminate-chorate detonator is illustrated in Fig. 3*a*. One fragment of the detonator shell is considerably larger than others and is probably a portion of the base of the detonator. The course of its flight has been changed which is evident by its wavering conical wave and its trail of eddy currents. The velocity of this particle, measured from the third photograph of this group, was 710 meters per second. Other particles of intermediate size follow across the field of view of the camera.

In the photographs of the discharge of No. 6 tetryl lead azide detonators which are shown in Fig. 3*b*, the fragmentation is more complete. The particles are small, more numerous, and moving at a measured velocity of 1900 meters per second for the more advanced particles. In contrast, a poor detonator, such as the experimental No. 8 lead styphnate proved to be, produces little fragmentation of the copper shell. A few relatively large particles followed the shock wave. Measurements made from the photographs in Fig. 3*d* gave the velocity of the particles as averaging 375 meters per second.

In photographs taken of the discharge of a No. 6 picric acid mercury fulminate detonator illustrated in Fig. 3*c*, particles of the detonator shell and gaseous products of detonation both pass through the shock wave. A tongue of opaque gases which pushes out through the shock wave and at first follows closely after the fragments of the detonator shell, is a feature not observed with any other detonator. The velocity of the particles preceding the gases was found to be 1620 meters per second.

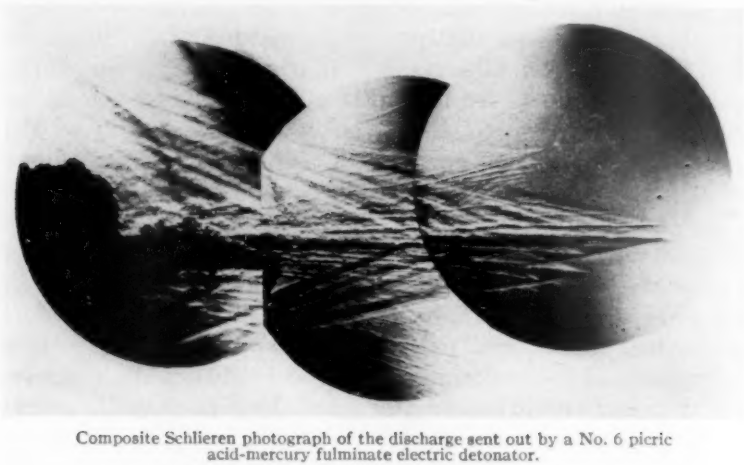
COMPOSITE INSTANTANEOUS PHOTOGRAPH.

A composite photograph of the discharge sent out by one of the No. 6 picric acid mercury fulminate detonators just referred to, is shown in Fig. 4. Photographs were taken of

[16] Cranz, C., "Lehrbuch der Ballistik," p. 36, Julius Sprenger, Berlin, 1925.

each of three separate shots with three positions of the camera (Fig. 2), and the time at which the exposures were made adjusted to allow matching of the individual pictures. The match of these photographs of course is not perfect since no two detonators send out flying particles exactly alike. Here

FIG. 4.



Composite Schlieren photograph of the discharge sent out by a No. 6 picric acid-mercury fulminate electric detonator.

the shock wave has overtaken the tongue of gases sent out, and the particles of the detonator shell are seen to be far in advance of the wave. A portion of the particles are moving straight away from the detonator but other particles are spreading out in their direction of travel.

WAVE SPEED PHOTOGRAPHY OF THE EXPLOSION OF A DETONATOR.

To obtain the velocity of the shock wave, continuous time and distance records were made utilizing the "wave speed" camera.[17] With this camera, the shock wave, solid particles, and gaseous products of explosion are photographed by means of the Schlieren method on a moving film through a slit 0.5 mm. in width. A shock wave viewed through a slit parallel to the line of fire from the detonator appears as a moving

[17] Gawthrop, D. B., Shepherd, W. C. F. and Perrott, G. St. J., J. FRANK. INST., 211, p. 67, 1931.

point which traces a line across a moving photographic film. The velocity of the wave is readily calculated from the slope of this line. Two such time and distance records are shown in Figure 5; one in which the particles from the explosion are in back of the shock wave, and one in which the particles have passed through the shock wave.

The average results of three determinations made from moving film photographs are given in Table 1, for the average velocity of the shock wave expanding spherically over a distance of 30 centimeters, which distance is the width of the field of view of the camera. The velocities of the shock waves initiated by eleven different samples of detonators were found to vary from 455 to 530 meters per second. The average deviation of the mean is 3.36 per cent., which indicates that the velocity of the shock wave should not be considered a means of classifying detonators. The weight and density of the charge of explosive in a detonator, the physical properties of the copper shell in which this explosive is placed, and the chemical composition of the explosive, are all factors which may affect the velocity of the shock wave from a given detonator.

The average velocity of the particles from the explosion are also included in Table 1. The velocities varied from 460 to 1950 meters per second, depending upon the type of detonator fired. It may be noted that particles of the copper shell are propelled with the greatest velocity by the explosion of detonators containing a primary initiating charge of explosive and a secondary base charge of less sensitive material.

The gaseous products of detonation expand in all directions and at first follow closely behind the shock wave, but their speed diminishes rapidly, averaging less than 100 meters per second at a distance of 15.0 cm. from the point at which the explosion took place.

An instantaneous photograph and a composite moving film photograph of the explosion of No. 8 lead styphnate detonators loaded in aluminum shells are shown in Fig. 6. It is a characteristic of detonators loaded in aluminum shells that particles of aluminum produced by the fragmentation of the shell burn with flame.[18] This flame is sent out in advance of

[18] Payman, W., *Trans. Institution of Min. Eng.*, **75**, p. 191, 1928.

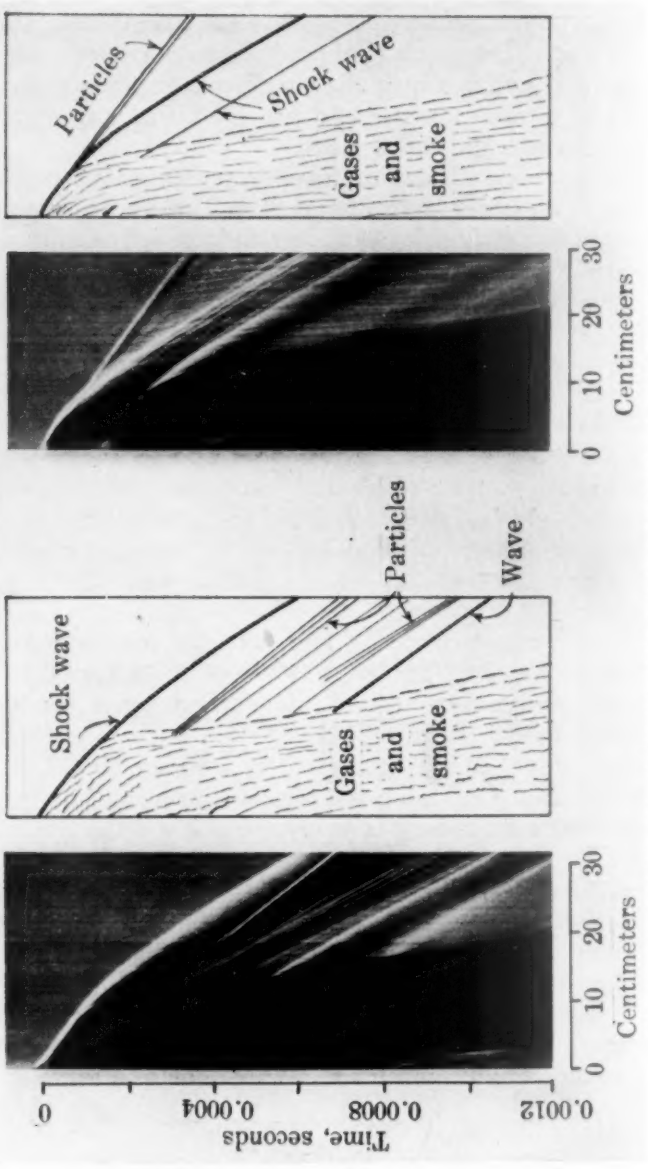


FIG. 5.

Moving film photographs of the disturbance sent out by electric detonators.

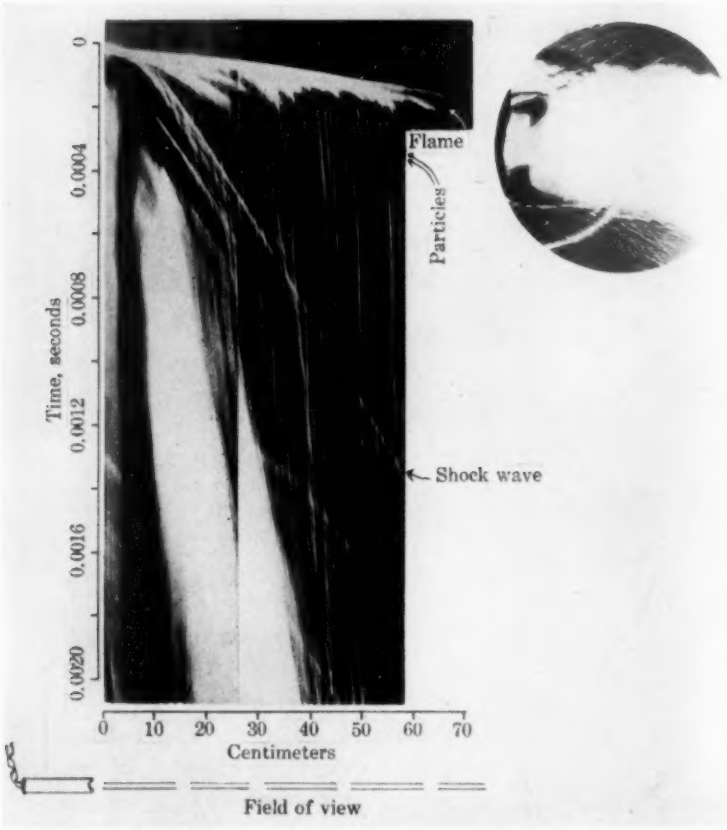
TABLE I.

Velocity of the Shock Wave and Particles Sent Out, and the Distance Detonation is Propagated by the Explosion of Electric Detonators.

Sample No.	Grade No.	Type of Electric Detonator, Classified According to Base Charge.	Weight of Charge, Grams.	Velocity of Shock Wave, Meters per Second.		Velocity of Particles, Meters per Second.		Length of Gap, cm.	
				In Air.	In Tube.	In Air.	In Tube.	Receiver 40 Per Cent. Straight Dynamite.	Receiver Permissible Explosive.
1	6	80–20 mercury fulminate potassium chlorate	1.05	490	965	890		125	80
2	6	do.	.95	505	1000	910		100	30
3	6	do.	1.03					80	50
4	6	Tetryl small initiator of mercury fulminate	.86	495	1130	1090		125	60
5	6	Tetryl primed with lead azide	.66	455	1185	1350	1405	400	30
6	6	Picric acid primed with mercury fulminate	1.25	530	1105	1325	1340	300	100
7	8	80–20 mercury fulminate potassium chlorate	2.12	485	955	875		90	40
8	L.O.X.	do.	1.51	500		970		175	30
9	8	Tetryl primed with mercury fulminate	1.34	470	1065	1235	1200	250	70
10	8	Lead styphnate	1.74	510	970	460		50	0
11	8	Nitromannite, mercury fulminate mixture	1.16	520	1030	780		90	35
12	8	Lead styphnate in aluminum shell		510		1590[1]			

[1] Average velocity of flame 4550 meters per second.

FIG. 6.



Explosion of a No. 8 electric detonator loaded in an aluminum shell.

the shock wave at an average velocity of 4550 meters per second. It is followed by particles propelled at a velocity of 1590 meters per second and finally by the shock wave advancing at an average velocity of 510 meters per second for the first 30 centimeters of its travel. Flame is also evident in the gaseous products of detonation.

VELOCITY OF THE SHOCK WAVE SENT THROUGH CELLOPHANE TUBES.

In firing explosives loaded in a borehole, the transfer of detonation from a shielded detonator to a charge of explosive

occurs within a tube and under these circumstances the velocity of the shock wave is higher than it is when expanding in air. The relative speeds of the shock wave sent through tubes by the explosion of detonators were obtained by means of the wave speed camera. A shielded detonator was placed at one end of a cellophane tube 3.2 cm. in diameter, and the shock wave sent through the tube by the explosion of the detonator was photographed on a moving film. A continuous record of its passage through the tube is thus obtained, since cellophane is transparent.

The average velocity of the shock wave within the tube over the first 30 centimeters of its travel is given in Table 1 for each type of detonator fired. The velocities thus obtained are approximately double those obtained for similar detonators when their shock waves expand freely in air.

Measurements of the average velocity of the particles when this velocity exceeded that of the shock wave were also made. It is difficult to distinguish with certainty the path of particles advancing back of the shock wave, since the cellophane tube is disturbed by the prior passage of the wave. An average increase in velocity of 197 meters per second was found for the particles in the tube over the average velocity of the particles sent out into the air by the same type of detonators, and this can be accounted for by the increased velocity of the wave through which the particles passed.

GAP TESTS.

The relative ability of the disturbance sent out by the explosion of a shielded detonator to transfer detonation to a charge of explosive was obtained from modified gap tests.[19] In these tests a detonator inclosed in a shield was separated from a cartridge of explosive by an air gap. The shield containing the detonator and the cartridge of explosive with the end facing the detonator cut off were wrapped in a paper tube. Explosion of the detonator propagates detonation over the air gap to the charge of explosive. In successive trials the length of the air gap is increased until detonation is not

[19] Comey, A. M., 7th Int. Cong. Appl. Chem., London, 1909, Sec. IIIb, p. 28. Munroe, C. E., and Tiffany, J. E., U. S. Bureau of Mines Bull. 346, p. 59, 1931.

transferred to the cartridge of explosive. Measurement of the limiting distance *d*, indicated in Fig. 7, over which detonation of the cartridge of explosive occurs in four trials, is taken as the distance detonation is propagated.

FIG. 7.

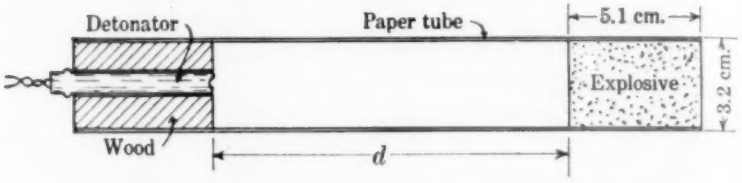


Diagram of a shielded detonator and explosive arranged for a gap test.

The results of these gap tests are given in Table 1, in which detonators initiated detonation to a charge of 40 per cent. straight dynamite or to one of a permissible explosive. With two exceptions the detonators used were commercial products classified according to their base charges and rated strengths. The two exceptions were special detonators made for experimental purposes (Samples 9 and 10).

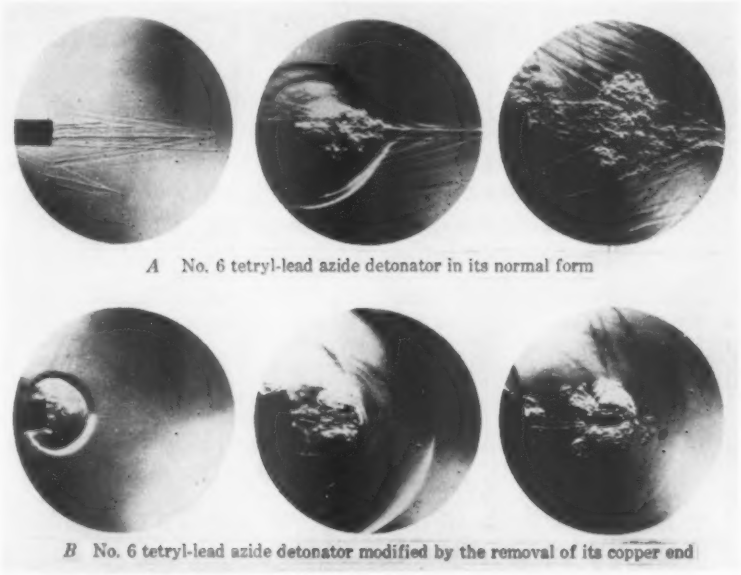
Detonation was propagated through a paper tube to a charge of 40 per cent. straight dynamite over a distance of from 50 to 400 cm., depending upon the detonator fired. Similarly detonation was propagated to a charge of permissible explosive over a distance of from 0.0 to 100 cm. The differences in the distances are considerable and the fact that detonation was propagated by two types of detonators over a distance of 300 and 400 cm. respectively, was a result which certainly was not expected.

The propagation of detonation to a charge of 40 per cent. straight dynamite by a detonator, over an air gap of 400 centimeters is a greater distance than is obtained when a charge of explosive is substituted for the shielded detonator. For example, under similar conditions of testing, a half cartridge of 40 per cent. straight dynamite primed with a No. 6 80–20 fulminate chlorate detonator propagated detonation in each of four trials a distance of 125 cm. It was also found that a No. 6 80–20 fulminate chlorate detonator propagated detonation over a distance of 125 cm. Other

detonators were found which propagated detonation over much greater distances, and from velocity measurements of the flying particles produced by the fragmentation of the detonator shell, it is suggested this increased distance of propagation is possibly due to the higher velocity and increased energy of the flying metal particles.

Propagation tests were repeated with a number of electric detonators from which the base of the copper shell had been cut, thus removing the source from which copper for flying fragments might be produced. This procedure greatly lowered the distance to which detonation was propagated to a charge of 40 per cent. straight dynamite. No. 6 80–20

FIG. 8.



A No. 6 tetryl-lead azide detonator in its normal form

B No. 6 tetryl-lead azide detonator modified by the removal of its copper end

Disturbance sent through a paper tube by the explosion of an electric detonator.

fulminate chlorate detonators thus treated propagated detonation in each of four trials over a distance of 20 cm. in place of 125 cm. for an uncut detonator of this type. Similarly, a No. 6 tetryl lead azide detonator so treated propagated detonation over a distance of 30 cm. in place of 400 cm. obtained with an uncut detonator of this type.

In Fig. 8, instantaneous Schlieren photographs are shown of the disturbance projected from the end of a paper tube by the discharge of a No. 6 tetryl-lead azide detonator in its normal form, and by a similar detonator modified by the removal of its base end. In (*a*) flying particles are shown as the first to emerge from the open end of the tube. Later views show the shock wave, air, and additional flying particles sent out of the end of the tube by the explosion. In (*b*) only the shock wave and a vortex ring of air is visible in the photographs. No solid particles appear, showing that the removal of the copper end of the detonator eliminated flying particles as a source of disturbance in a gap test.

A comparison of the speed of the shock wave initiated by the explosion of a No. 6 tetryl-lead azide electric detonator with the speed of the shock wave sent out by a similar electric detonator modified by the removal of its copper end was obtained from wave speed records. Measurements of the average speeds of the shock waves over the first 30 cm. of travel are given in Table 2. It may be seen from Table 2 that the removal of the copper end of the detonator results in an increase in speed of 48 per cent. for a shock wave sent out in air and an increase in speed of 30 per cent. for a shock wave sent through a cellophane tube.

TABLE 2.

Comparative Speeds of the Shock Wave Sent Out by the Explosion of an Electric Detonator and a Similar Electric Detonator with Its Base Removed

No. 6 Tetryl-lead Azide Electric Detonator.	Velocity of Shock Wave, Meters per Second.	
	Normal Form.	Base Removed.
Unconfined	455	675
In cellophane tube	1185	1540

Although the removal of the copper end of this detonator increases the speed of the shock wave sent out by the explosion, the distance to which detonation is propagated to a charge of explosive is greatly decreased, which indicates that the copper particles produced by the fragmentation of the copper shell are an important factor in the propagation of detonation by a detonator.

If a gap test is made without the paper tube connecting the shielded detonator and charge of explosive, the distance

detonation is propagated to a charge of 40 per cent. straight dynamite is of the order of 50 cm. or less, by either a No. 6 or No. 8 fulminate chlorate, or No. 6 tetryl azide detonator. An explanation for this decreased distance over which detonation is propagated is found in the absence of a shock wave of high velocity. This wave expands spherically, which results in a rapid dissipation of its energy over an ever increasing area.

CONCLUSIONS.

The following conclusions may be drawn from the data presented:

1. Detonators containing a base charge of explosive such as tetryl or picric acid, primed with an appreciable amount of a sensitive initiating explosive such as mercury fulminate or lead azide, transfer detonation over the greatest distances. With this type of detonator the photographic data indicate (*a*) the particles of the metal shell produced by the explosion are more finely divided; (*b*) the velocity of the particles sent out by the explosion is 1200 meters per second or greater as compared to a velocity of 970 meters per second, or less with other types of detonators.

2. (*a*) The shock wave in air initiated by the explosion of an electric detonator has an average velocity of 497 meters per second for the first 30 centimeters of propagation. The average deviation of the mean from this value is 3.36 per cent. which includes velocity determinations obtained by firing No. 6 and No. 8 electric detonators having copper shells and with a detonator having an aluminum shell.

(*b*) The average velocity of the shock wave sent through a cellophane tube by the explosion of a shielded detonator is 1045 meters per second for the first 30 centimeters of its travel. The average deviation of the mean of this value is 2.16 per cent.

DISCUSSION.

To transfer detonation from a detonator to a cartridge of explosive over a relatively long air gap, the disturbance sent out by the explosion of the detonator must be capable of raising the temperature at any point in the cartridge of explosive sufficiently to bring about its detonation. The

raising of the temperature at any point will depend upon the energy and time element of the shock to which the explosive is subjected. No widely destructive effects are required, only that a portion of the explosive shall be raised to an appropriate temperature to cause detonation. These conditions are often fulfilled when flying pieces of copper and the shock wave, sent through a paper tube by the explosion of a detonator, strike the cartridge of explosive. Occasionally, incomplete decomposition is produced which is evidenced by burning of the cartridge of explosive in place of its detonation.

In a tube, the time interval between the arrival of metal particles and the shock wave is small, which results in a rapid series of shocks at the surface of the explosive. The particles of copper in themselves were shown to be not as effective in initiating detonation over as great a distance as the combined action of the particles and the shock wave, since the removal of the paper tube does not materially alter the speed of the particles but causes the shock wave to arrive at the surface of the explosive much later. Neither is the shock wave alone effective in transferring detonation over the same distance. The removal of the copper end of the detonator prevents the sending out of flying pieces of copper but increases the speed of the blow struck by the shock wave.

Particles of metal are shot out by different detonators at different velocities and the work done consumes variable amounts of the total energy available. If the energy utilized by the metal particles is a large proportion of the total energy, it probably accounts for the uniform velocity of the shock wave sent out by the explosion of detonators containing either 1.0 or 2.0 grams of a mercury fulminate-chlorate mixture.

EXPLOSIVES SECTION, PITTSBURGH EXPERIMENT STATION,
U. S. BUREAU OF MINES, PITTSBURGH, PA.,
June 6, 1932

COSMIC RAYS—THEORY AND EXPERIMENTATION.*

BY

THOMAS H. JOHNSON, Ph.D.,

Assistant Director, Bartol Research Foundation of The Franklin Institute.

One would not be far from the truth in saying that never before in the history of science, certainly not in recent times, has there been a subject about which so many able investigators have so strongly disagreed as they do on questions concerning the cosmic radiation.

The controversies have been especially intense because of the wide-spread interest in the cosmic ray work, incited by the far-reaching implications of any new discovery or interpretation. In fact the cosmic ray is not only occupying a position of increasing importance in physics, but it is invading the fields of astronomy, geology, meteorology, and cosmology.

Of special interest to the physicist, however, is the relation of the cosmic radiation to nuclear physics.

The discovery of the electron as a tool for investigation in the year 1895 marked the beginning of the science of atomic physics. Within the next few years not only was it apparent that all matter was composed of some 92 different kinds of atoms, but it was also realized that each atom consisted of a positively charged nucleus about which circulated a certain number of negatively charged electrons. By the end of 1930 a feeling of confidence had pervaded scientific circles that practically all of the fundamental laws of motion and interaction of these external electrons were well understood, but in comparison with this progress, notwithstanding a great deal of effort, practically nothing had been learned about the structure and the mechanics of the central nucleus. One of the principle reasons underlying this lack of progress was the handicap under which the nuclear physicist was working in not having rays of sufficient power for his purposes. Arti-

* Presented at the Stated Meeting held Wednesday, October 19, 1932.

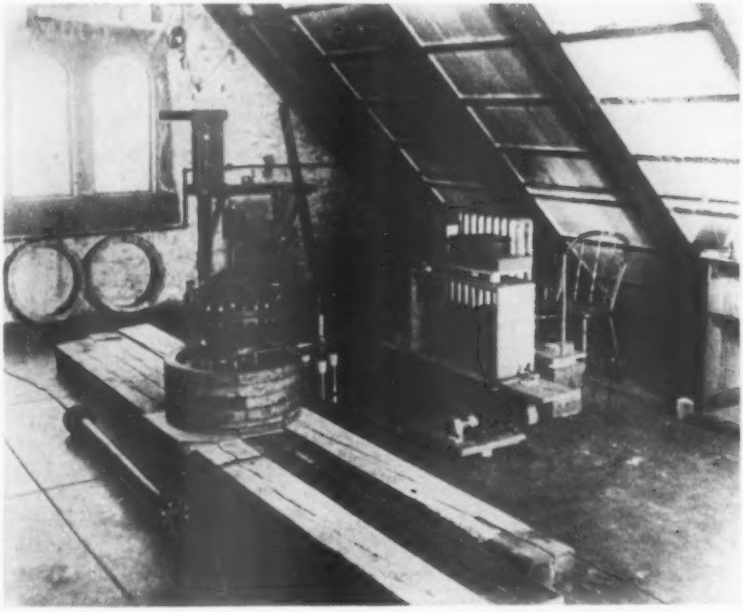
ficially generated electron rays had made their attack on the exterior structure of the atom, but whereas in this problem rays from ten to ten thousand volts were sufficiently energetic, in the nuclear problem, from one to tens of millions of volts were required, and only at the threshold of this range have rays been artificially produced. From this aspect, therefore, the cosmic rays have attracted a great deal of interest, for therewith, at the very limit where man is failing to create his own tools, nature is supplying the demand.

These rays enter our atmosphere from sources as yet unknown in such small numbers that their presence can scarcely be detected and, were we not equipped with special highly sensitive instruments, they would never have been noticed. Yet these rays individually are the most potent of which we have any knowledge. In fact, if their numbers were increased to equal the rays of light which fall on the earth from sun, the most of the matter which now exists on the surface of the earth would be transmutted into other elements within about a month and the temperature of the earth would be raised to more than ten times that of the sun.

Cosmic rays were discovered and much of our knowledge concerning them has been gained through the use of an instrument known as the ionization chamber. One of these instruments designed by Swann is shown in Figs. 1 and 2. It consists of a hollow metal sphere filled with gas and provided with an internal insulated electrode. When a battery is connected to this electrode any electrical charges generated in the gas are swept to its surface and a current is measured. Such electrical charges are produced by any ionizing radiation capable of penetrating the walls of the vessel. For example, if radium is brought near the chamber the current to this electrode is increased or if the vessel is shielded by absorbing material from the rays emitted by the radioactive material in the atmoshpere and the surrounding rocks this current is considerably reduced. Rutherford, and McClennan noticed however, in 1903, that this small residual current could not be entirely eliminated even by shielding the vessel with considerable thicknesses of lead and this observation found its explanation in the supposition that a more highly penetrating radiation than had been associated with any of the radioactive

disintegrations was entering the vessel. Gockel in 1909, and Hess, and Kohlhörster, in 1912, sent up balloons with self registering apparatus and showed that the intensity of this penetrating radiation increased with the elevation above the earth's surface. Thereby they disproved the hypothesis that these rays originated on the earth and showed that they were probably of cosmic origin.

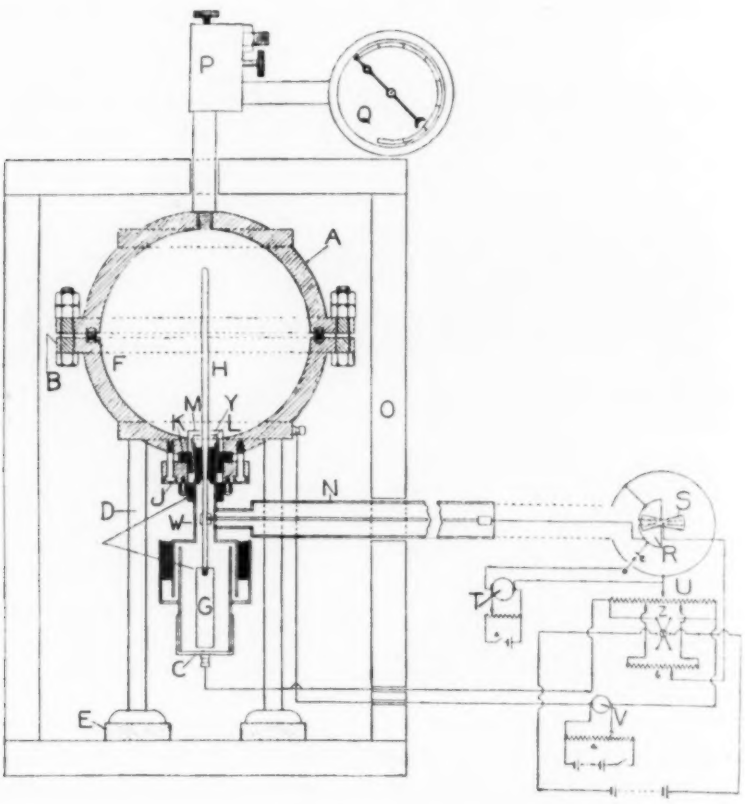
FIG. 1.



But what the rays are, is still a debated question. Some investigators believe them to be electromagnetic waves similar to but more penetrating than the gamma rays of radioactivity. Others find evidence that they are electrons of enormous energies, or possibly protons, and still others find that neither of these assumptions fit the facts but that some third type of radiation is required for their explanation. The puzzle is a difficult one for we have no previous knowledge of the behaviour of any of these radiations within the energy range of the cosmic rays. Artificially produced electron rays accelerated

by one hundred thousand volts will penetrate only a few thousandths of an inch of the lightest metals, the fastest known beta rays from radium, which are electrons of millions of volts energy, will penetrate a few sixteenths of an inch of the same material. X-rays are stopped by a quarter of an inch

FIG. 2.

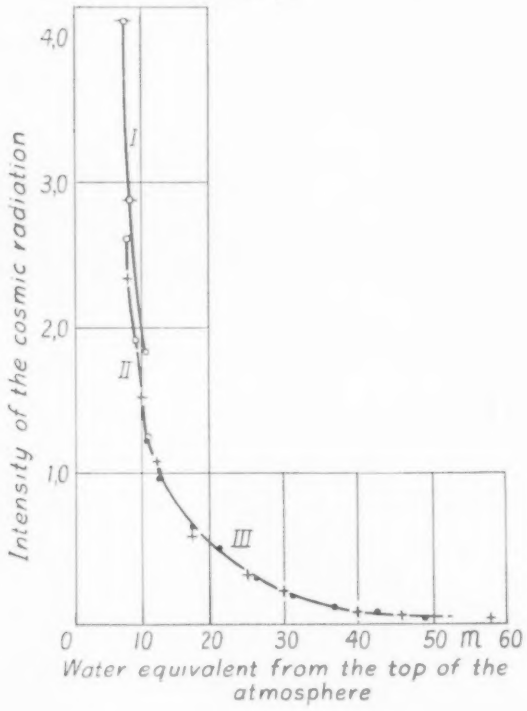


of lead, and gamma rays by an inch of lead, but cosmic rays will penetrate several yards of lead and a measurable amount of cosmic radiation has been found an eighth of a mile below the surface of the sea.

The absorption of these rays has been studied principally by Millikan and by Regner, and their results are represented

by the curve in Fig. 3, where the depth below the top of the atmosphere is represented by the number of meters of water equivalent to the absorbing material above the apparatus. On top of the mountain peaks the radiation is comparatively strong, falling off as the measuring apparatus is lowered. At sea level the absorption in the atmosphere has reduced the intensity to one-third of its value on Pike's Peak and in seventy

FIG. 3.



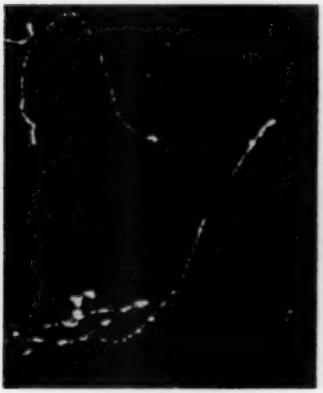
meters of water it is only one-twentieth of the sea level intensity.

These results which were obtained comparatively early in cosmic ray history have been the subject of a great deal of speculation concerning the origin and the energy of the cosmic rays but it now appears that until we know more about the interaction with matter of radiations of these enormous pene-

trating powers it will be impossible to arrive at any very certain conclusions from information of this type.

A beginning on the problem of the interaction of the cosmic rays with matter was made in 1929 by Skobelzyn. Taking advantage of the fact that water vapor from supersaturated air has a tendency to condense out in the form of droplets

FIG. 4.



Curved β track.

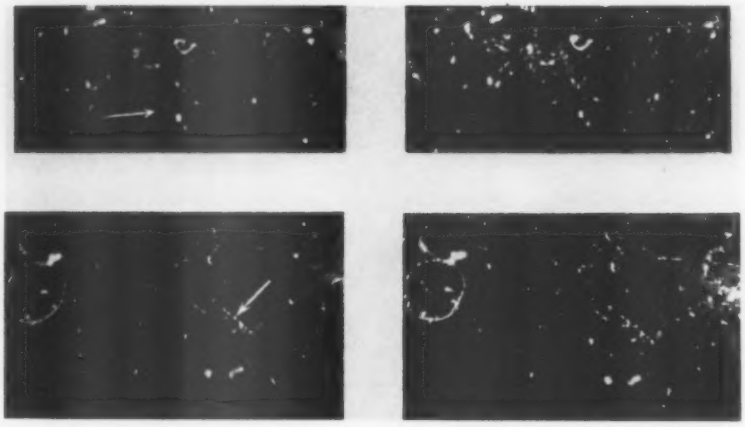
Straight β track.

β track showing nuclear deflection and electronic collision.

around electrically charged molecules he was studying the trail of ions left behind the beta rays from radium. Photographs of these thread-like clouds are shown in Fig. 4; each droplet in the thread representing one of these charged molecules or ions. Subjecting the cloud chamber to the action of a powerful magnet the paths of the rays were curved, as shown

in Fig. 5, by the force of the magnetic field acting upon their electrical charges and from the curvatures Skobelzyn was able to measure their energies, for the less a track is curved the higher is the energy of the ray which produces it. In some of these photographs in spite of the powerful magnet some of the tracks, marked by arrows in Fig. 5, appeared straight although in other respects they were very similar to the beta ray tracks. If these were also produced by electron rays similar to the beta rays their energies must have been over fifteen million volts and therefore they were definitely outside of the range of the rays from radioactive disintegrations.

FIG. 5.



β-ray tracks curved by a magnetic field. (Skobelzyn.)

These were probably associated in some way with the cosmic rays and this discovery of the tracks of cosmic ray particles in the cloud chamber paved the way for some remarkable developments, for herewith it became possible to study the rays individually.

In the same year a third method of investigation was being developed by Bothe and Kohlhörster. Their apparatus, patterned after an idea of Geiger and Mueller, consisted of a metal cylinder and a wire stretched along its axis. (Fig. 6.) The arrangement was enclosed in a glass tube filled with about a tenth of an atmosphere of air and a negative potential

of about 1500 volts was applied to the metal cylinder. Whenever an electron is liberated inside of the cylinder by the action of some ionizing ray it is swept to the central wire under the influence of the electric field with such rapidity that it too becomes an ionizing ray and atoms along its path are split up into positively and negatively charged particles. These charges, in turn, become ionizing rays and the process is cumulative. The result is that a single electron can set off a flow of a charge which is great enough to be amplified and recorded. The tube is also provided with a device which stops the discharge after a certain amount of charge has flown and allows

FIG. 6.

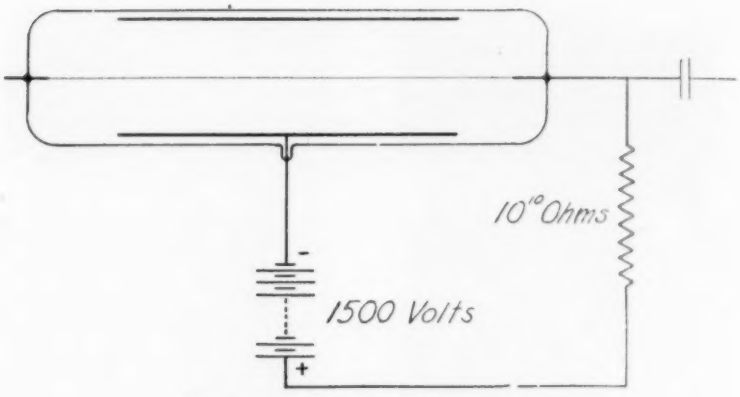


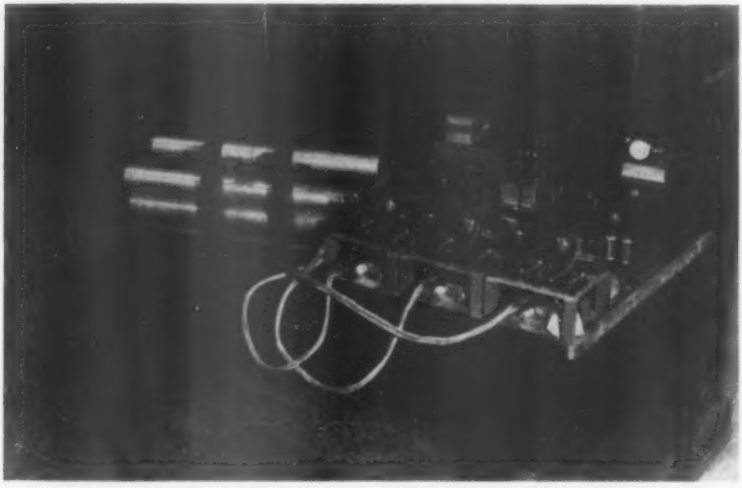
Diagram of a Geiger-Mueller electron counter.

the tube to recover again so that it will be ready for the next electron to be liberated by another ionizing ray. Thus the discharges enable one to count the individual rays as they pass through the tube. This can be done by connecting the tube through amplifiers to a loud speaker or a recording device. Some of these rays, thus recorded, are the ionizing cosmic rays themselves, whereas others are ionizing electron rays generated from the walls of the tube by the non-ionizing gamma rays from the radioactive materials in the surrounding air and rocks.

This instrument, however, is unable to distinguish between the radioactive rays and the cosmic rays for the counter tube

gives the same response to both of these types of radiation. A very simple and satisfactory modification of this apparatus, however, enables this distinction to be made. The radium rays are capable of effecting only one of these tubes at a time, the reason for this being that the penetrating radium rays are non-ionizing rays and are capable of discharging a counter only after they have converted their energy within the counter itself into easily absorbable electron rays. On the other hand an ionizing cosmic ray is itself able to pass through two or, for that matter, any number of counter tubes if they are placed

FIG. 7.

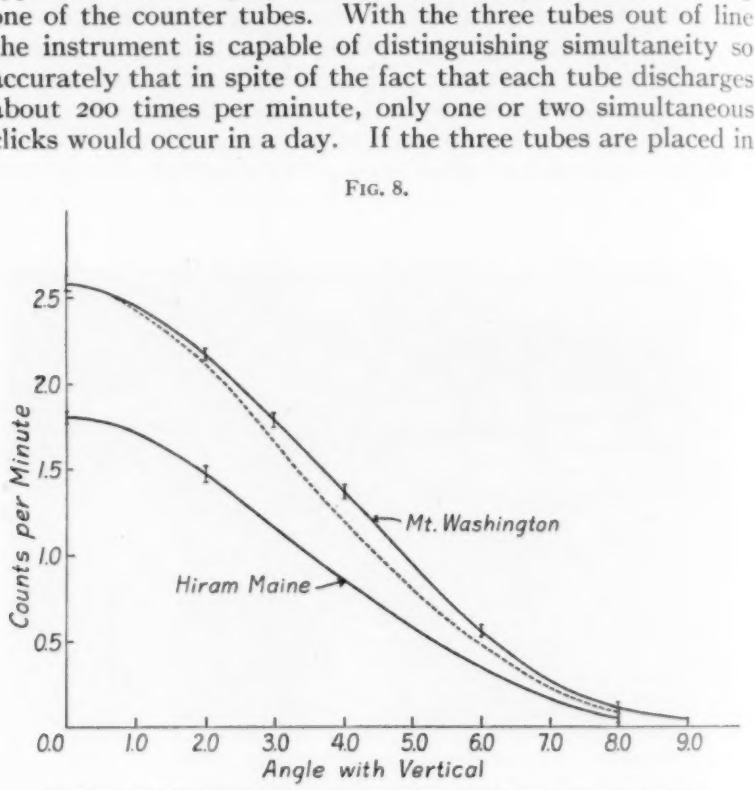


Apparatus for recording triple coincidences designed by Johnson and Street.

in a line and it can discharge every tube through which it passes. Since the rays are moving with nearly the velocity of light these tubes would therefore be discharged nearly simultaneously. To observe the cosmic rays alone without the disturbing influence of the radium rays it is only necessary to arrange the circuits so that only the simultaneous discharges are recorded, and this can be easily done. Not only will the instrument when modified in this way count only the cosmic rays, but it selects only the cosmic rays which are included within the portion of space which is cut out by the areas

of the counter tubes. In other words, it constitutes an automatic cosmic ray telescope which counts the rays passing through it. An arrangement of counters and circuits of this type is shown in Fig. 7, each of the metal cylinders containing one of the counter tubes. With the three tubes out of line the instrument is capable of distinguishing simultaneity so accurately that in spite of the fact that each tube discharges about 200 times per minute, only one or two simultaneous clicks would occur in a day. If the three tubes are placed in

FIG. 8.

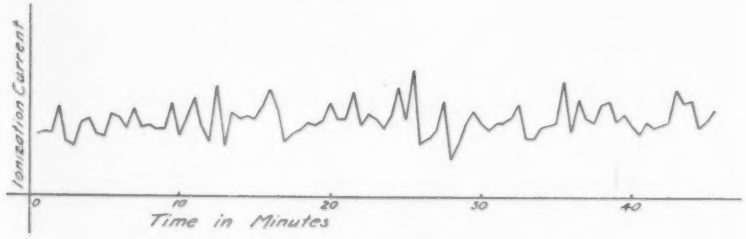


Variation of triple coincident counting rate with the angle of the counter telescope.

line and close together so that penetrating cosmic ray corpuscles may pass through all three, about three simultaneous discharges occur every minute these being produced entirely by the cosmic rays, and the apparatus thus arranged is completely insensitive to the radioactive rays. Whereas the average rate of incidence of the cosmic rays from the vertical direction is about one every twenty seconds, if the tubes were placed in the horizontal direction the rate would fall off to about two per cent. of this or about three per hour. The results

obtained by Street and the writer for this distribution in angle about the vertical on the top of Mt. Washington and at 600 ft. elevation at a nearby station in Maine is shown in Fig. 8. These results are the product of several days of counting and their accuracy is indicated by the vertical lines. Not only is the counting rate faster at the higher elevation but the *distribution* about the vertical is different, for if the lower curve is increased in proportion to the vertical counting rates the dotted curve results. It is interesting to compare these results with the results of the measurements made with the ionization chamber, for one might expect that the ionization currents would be proportional to the number of rays unless the ionizing power of the rays found at the higher elevations differed from that of the rays at the lower elevations. It is

FIG. 9.



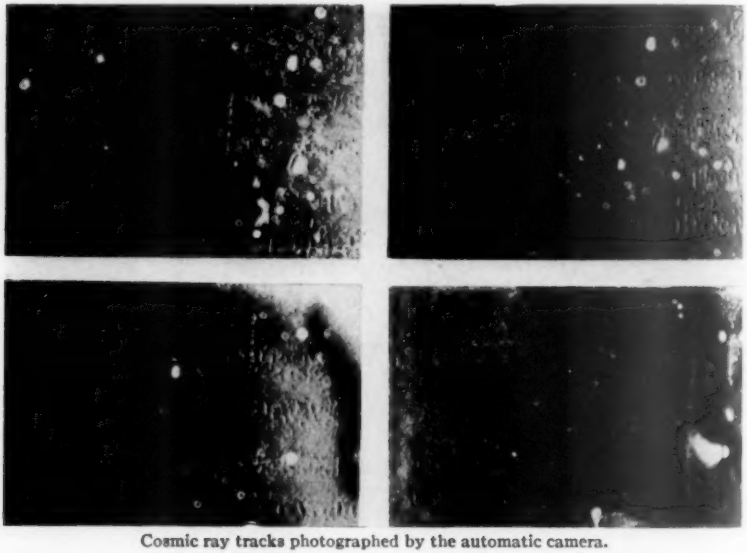
Fluctuations of the ionization produced by cosmic rays.

found that the ratio of the total number of rays at the two elevations is 1.5 whereas in an unshielded ionization chamber the ratio of the currents found by Millikan is 2.0. This difference between the ratio of number of rays and the ionization produced by them means, of course, that the rays at the higher elevations produce more ions on the average over a definite path length than the rays at the lower elevations, for the ionization falls off more rapidly than the number or rays. It should be possible to make some interesting deductions from these data concerning the absorbability of the rays, for the distribution is determined by the difference in the paths of the rays which come from the different directions. Before much progress can be made on this problem, however, it would be necessary to have data for a wider range of elevations than

that now available, this being the first time that comparable measurements of the distribution have been made at different elevations.

Whereas the ionization chamber measures the number of ions generated by the cosmic rays the counter method determines the number of rays which pass through the area of the counters. This area is easily determined so that the average number of rays per square centimeter from any direction can be determined. The result is that about 1.59 rays cross one

FIG. 10.



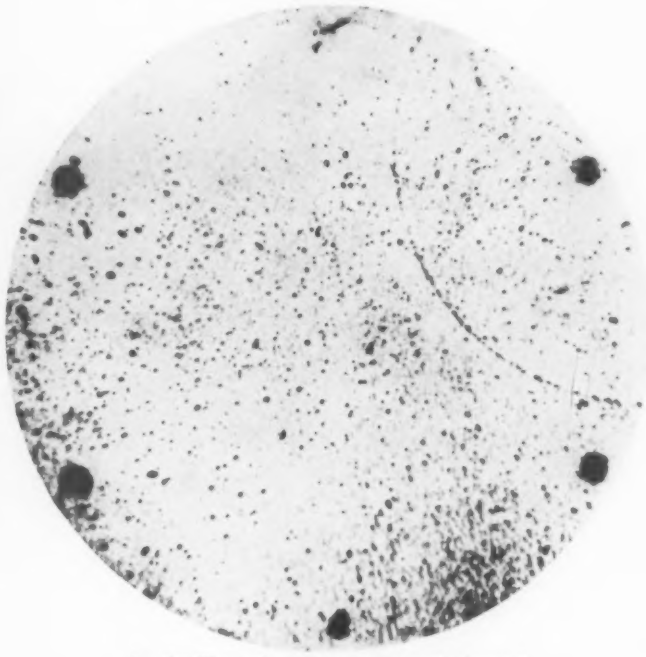
Cosmic ray tracks photographed by the automatic camera.

square centimeter per second from all directions at sea level. It is perhaps easier to remember that about twelve rays pass through the average sized man every second.

A remarkable agreement with this result has recently been obtained by Street from ionization measurements. Although the ionization chamber measurements give primarily the ionization produced by the rays, it is possible to calculate the number of rays from the fluctuations in the ionization current. A typical record of the ionization current upon which Street's calculations were based is shown in Fig. 9. The variations

confirm the individual discharges of the counters in showing that the rays enter the apparatus one at a time and liberate individual groups of ions. One readily appreciates the fact that if a current of a certain size is made up of a few large groups the fluctuations will be greater than if there are many small groups. Similar in principle are the variations in daily volume of trade in a business. The variations for example would be considerably greater for the piano merchant than

FIG. 11.

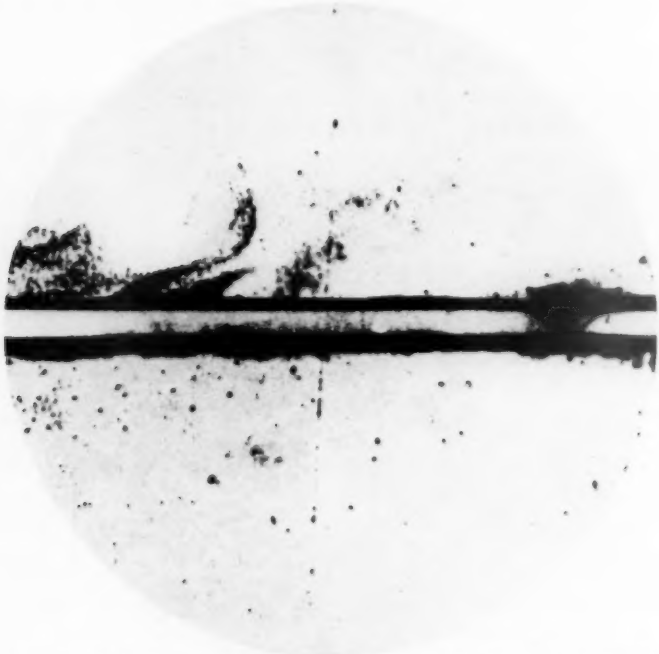


An 18 million volt cosmic ray track. (Anderson.)

for the five and ten cent store dealer doing the same volume of business. In fact the fluctuations are in a sense a measure of the number of individual purchases. In the case of the cosmic ray fluctuations the calculations show that 1.53 rays cross a square centimeter every one hundred seconds. This agreement with the figure of 1.59 determined from the counters gives us confidence that the two instruments are concerned with the same phenomenon.

A correlation between the results of the counters and the cloud chambers has also been obtained by Mott-Smith and Locher. These investigators operated a cloud chamber while just above it were two counters. If either counter discharged while the photograph was being taken the picture was marked for identification. Upon examining the photographs obtained in this way it was found that a large percentage of the marked

FIG. 12.

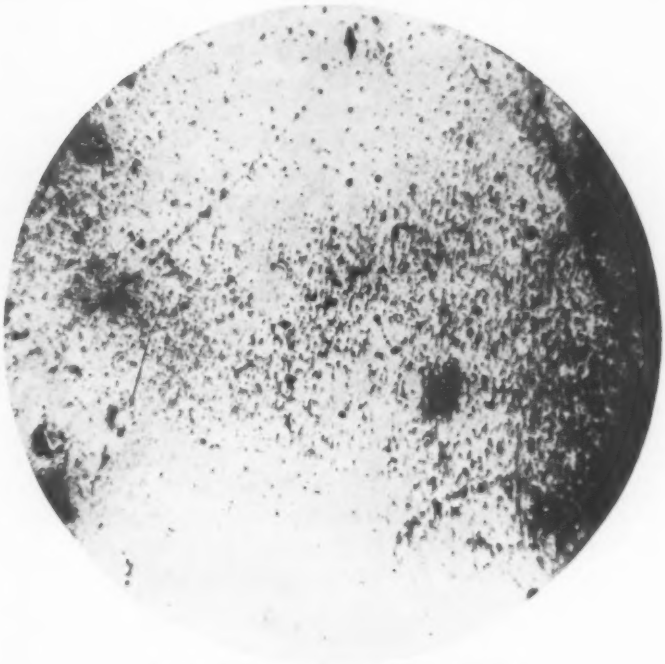


A cosmic ray track of energy greater than 600 million volts passing through lead. (Anderson.)

photographs contained tracks in the direction of the counters. This experiment was made somewhat more definite perhaps by an arrangement which Street, Fleisher and the writer were using in an investigation preliminary to another investigation which is still in progress. In this arrangement two counters were arranged so that the line joining them passed through a cloud chamber. The apparatus worked automatically in such a way that, whenever a coincident discharge of the two counters

took place during the short interval when tracks were forming in the chamber, a flash lamp was exploded which took the photograph. With this arrangement out of fourteen photographs which were taken, ten contained tracks which would have passed through the counters, four of these are shown in Fig. 10. It is clear therefore that the same rays which discharge the counters also produce the cloud tracks. All

FIG. 13.



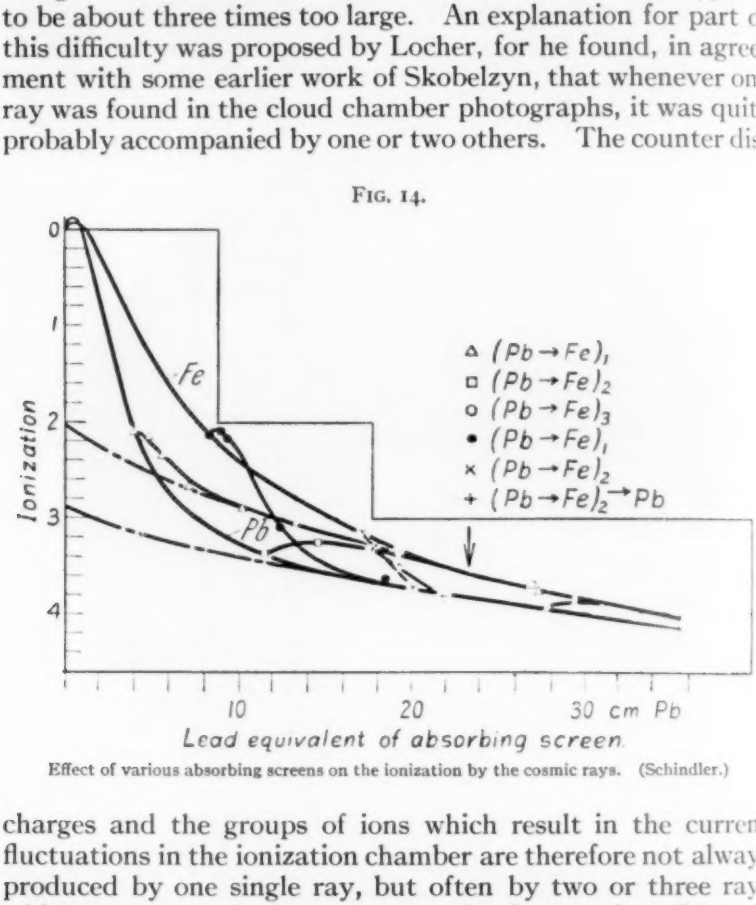
A group of two cosmic ray tracks. (Anderson.)

three methods are therefore dealing with the same phenomenon and their results may be compared.

By applying such a comparison we may advance another step in the problem of interaction of the cosmic rays with matter. The current in an ionization chamber containing a pressure of one atmosphere due to the cosmic rays alone corresponds to the production of about two and one-half ions per cc. per second at sea level. Dividing this figure by the

number of ionizing rays per square centimeter, we find that each ray produces 165 ions along one centimeter of its path. If this figure is compared with the number of droplets formed along a centimeter of the track in a cloud chamber it appears to be about three times too large. An explanation for part of this difficulty was proposed by Locher, for he found, in agreement with some earlier work of Skobelzyn, that whenever one ray was found in the cloud chamber photographs, it was quite probably accompanied by one or two others. The counter dis-

FIG. 14.



Effect of various absorbing screens on the ionization by the cosmic rays. (Schindler.)

charges and the groups of ions which result in the current fluctuations in the ionization chamber are therefore not always produced by one single ray, but often by two or three rays which pass through the apparatus simultaneously. There is however some remaining difficulty in accounting for as many as 165 ions per centimeter on the group hypothesis and further work is required to clear up this point.

Before returning to the question of the origin of these groups of rays it is necessary to describe some very important and enlightening work of Anderson. Improving on the

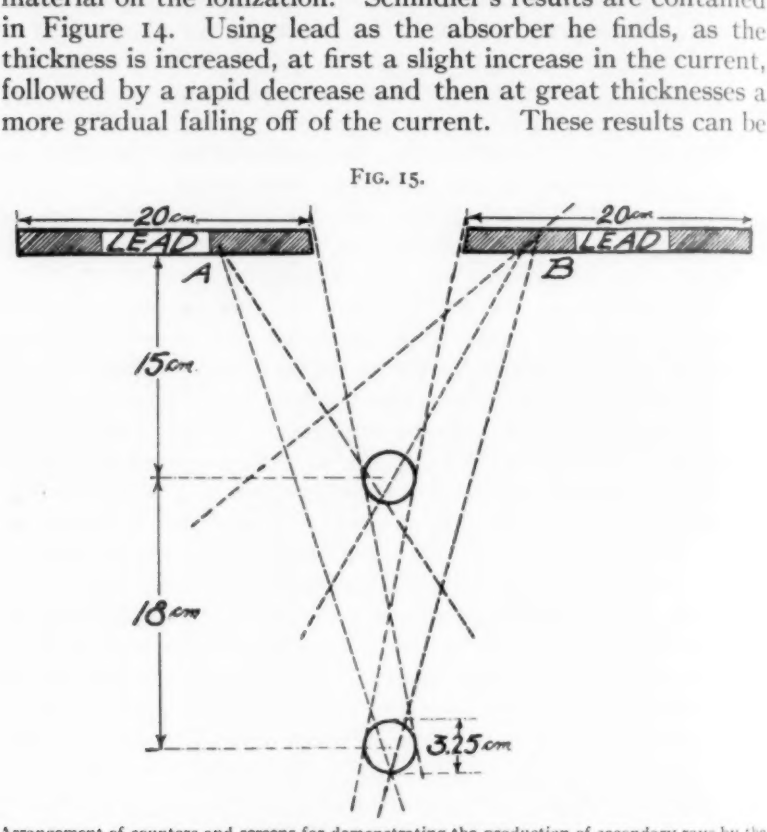
arrangement of Skobelzyn he has been photographing the tracks of the cosmic rays in a could chamber subjected to still more intense magnetic fields. Whereas in Skobelzyn's work rays of fifteen millions of volts of energy appeared straight, Anderson has been able to bend rays of energies of 600 million volts. Figure 11 shows one of Anderson's tracks corresponding to eighteen million volts of energy and Fig. 12 shows a track apparently straight and therefore of energy greater than 600 million volts. It is interesting that this ray has passed through a six millimeter lead plate and still has not been slowed down below the 600 million volt limit of measurement. What its energy is, we will perhaps some day measure, but at present we can only guess.

Returning now to the question of the groups of rays, Anderson's photographs have revealed the answer to the question of their origin, for Fig. 13 shows such a group of rays exposed to the action of the magnetic field. The two rays have apparently a point of common origin in the metal walls of the chamber. The evidence that the cosmic rays are of extra-terrestrial origin has already been presented. What interpretation therefore can be placed upon this new fact that two or more rays have originated from a nearby point? Obviously either one or perhaps both of these rays are secondary rays. The primary ray which has penetrated the atmosphere may be one of the two rays whose tracks are visible, or it may be a non-ionizing ray which shows itself only through its production of such high energy secondary rays. This is a question to which I shall return. It is a striking fact that one of these rays is curved in one direction while the other is curved in the opposite direction. This means that one of the rays carries a positive charge, and if the positive ray is a secondary, it must have originated from an atomic nucleus, for it is only from the nucleus of the atom that positive charges can be obtained, the external electrons being entirely negative.

The phenomenon of the production of secondary rays also shows itself in the ionization measurements, and in the counter experiments. Schindler, working with the ionization method, measured the current produced by the cosmic rays after they had passed through various thicknesses of absorbing material. His apparatus consisted of two ionization vessels, the dif-

ference in the currents being measured. Various thicknesses of absorbing material were placed above one of the chambers so that the difference current measured only the effect of that material on the ionization. Schindler's results are contained in Figure 14. Using lead as the absorber he finds, as the thickness is increased, at first a slight increase in the current, followed by a rapid decrease and then at great thicknesses a more gradual falling off of the current. These results can be

FIG. 15.



Arrangement of counters and screens for demonstrating the production of secondary rays by the cosmic radiation. (Johnson & Street.)

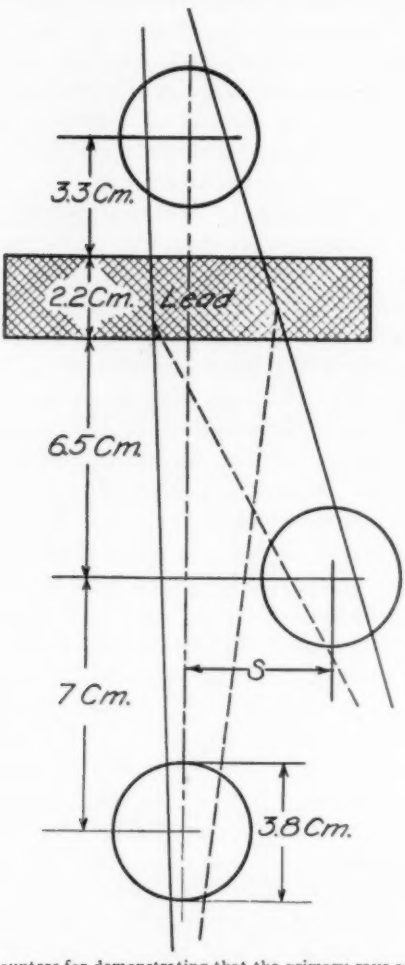
very accurately explained if we suppose the original increase is due to secondary rays generated in the lead by the primary rays so that their ionizing power is increased. The sudden drop in current is to be accounted for by the absorption in the lead of secondary rays which have been produced in the air above the apparatus, and the gradual change at the tail of the curve is due to the absorption of the primary rays after they have come fully into equilibrium with their secondaries in lead.

An analysis of the data permits a determination of the range of the secondaries from various media in various other media. You will notice for example that the curve obtained by using iron is quite different from that obtained with lead as the absorbing screen, even though a correction has already been made for the difference in the densities of the two substances. Apparently again the interaction of the cosmic rays with matter is a nuclear phenomenon for it is only on this basis that it is possible to account for the differences in these curves. In fact, the results of the analysis of Schindler's curves may be summed up in the following statements. I. The penetrating power of a secondary cosmic ray depends upon the nuclear type in which it was generated, the more penetrating rays being produced in the elements of low atomic weight. II. The absorption of the secondary rays is again a nuclear property of matter and elements of higher atomic weight are the best absorbers even after allowance is made for their greater density. III. Primary rays are absorbed most rapidly in elements of low atomic weight and, IV, secondary rays are generated most abundantly in elements of high atomic weight.

There are still many unanswered questions associated with the production of secondary rays. In fact, it is at this point that the cosmic rays have their closest relation to the still dark subject of nuclear physics, but it is not difficult to predict that this aspect of the subject will experience remarkable developments within the years before us. The methods at our disposal show great promise, and the work is still very much in its infancy. In this regard the coincidence counting method seems particularly hopeful. Using the arrangement of counters shown in Fig. 15. Street and the writer showed again the existence of groups of secondary rays and the experiment illustrates the counter method of dealing with the problem. When the lead was placed in the position shown, the counting rate of double coincidences was increased and, since the lead is nowhere in line with both counters, this increase must have been caused by a group of rays. Such a group could have been produced according to any one of three possibilities. I. A primary non-ionizing ray may generate from a single nucleus two or more ionizing rays, which diverge in such a way that some of them pass through

one counter and others through the other counter. II. A primary non-ionizing ray may generate two or more secondary ionizing rays from different nuclei. III. The primary

FIG. 16.

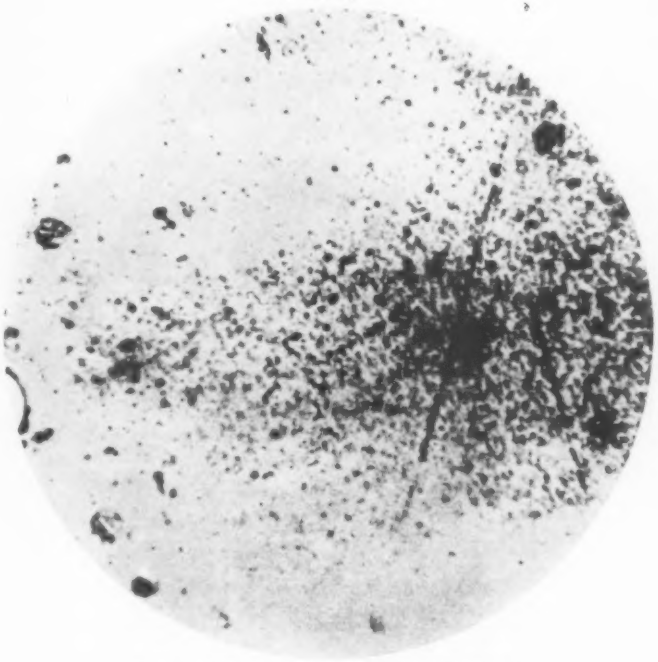


Arrangement of three counters for demonstrating that the primary rays are of the ionizing type. (Street & Johnson.)

ray may be an ionizing ray, in which case it is only necessary to invoke the production of a single secondary ray as the primary passes through the lead. To distinguish

between these possibilities we made experiments with the arrangement of counters shown in Fig. 16. The lead was placed between the top counter and the lower two counters and triple coincidences were recorded. If the secondaries were generated by a non-ionizing ray one would reason that any groups generated in the lead and showering downwards could not have produced triple coincidences so that the effect

FIG. 17.

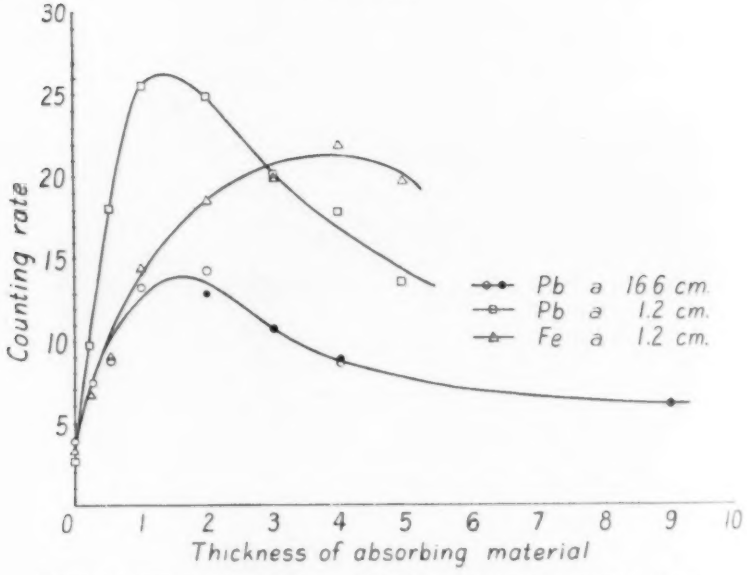


A group of three cosmic ray tracks. (Anderson.

of the lead would only show itself in case some of the secondaries went upwards, and it was expected that the number of such cases would be small. Not only did the lead still have an effect in producing additional triple counts but the number of such counts was sufficient to account for the entire effect of the lead in the double counting experiment just cited. The results of this experiment therefore limits the possibilities for the production of groups of secondary rays to that in which

the primary ray is itself an ionizing ray and this must be regarded as strong evidence that the rays which enter our atmosphere from the outside are of the nature of electron rays. The photograph of Anderson's in Fig. 17 shows a group of three rays, and it is easy to imagine that the straight track in the center is that of a primary ionizing ray which, though it has given up some hundred millions of volts of energy to the two secondaries, still possesses more than 600 million volts.

FIG. 18.



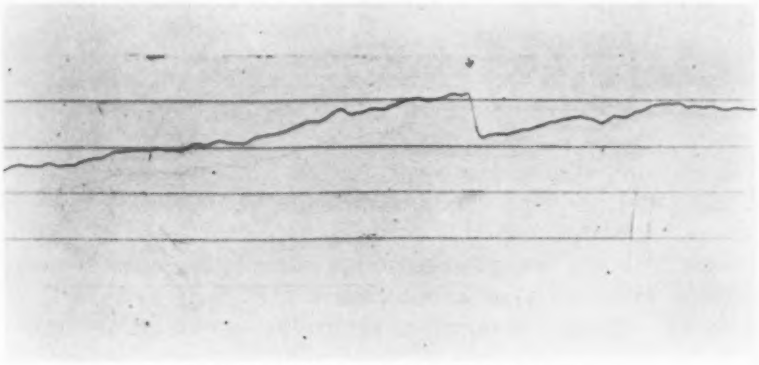
Variation of number of secondary rays with thickness of absorbing material. (Rossi.)

The secondary rays have also been studied by Rossi using an arrangement of three counters, not in line. Various thicknesses of absorbing material were placed above the counters and the variations of the counting rate shown in Fig. 18 seem very suggestive though to the writer's knowledge no satisfactory interpretation has been given.

The formation of these secondary rays may be considered as mild nuclear upsets. Explosions of a much more drastic character also occur, though much more rarely. These have been observed in the ionization chamber first by Hoffman and

since then by several others, in particular by Steinke and Schindler. Records of these explosions obtained by Swann and Street are shown in Fig. 19. The sudden burst of current corresponds to the production of more than ten million ions. A single ray in traversing the chamber will produce about ten thousand ions and this may mean that a cosmic ray has been able to liberate at one time from the surrounding nuclei one thousand secondary rays each perhaps having energies of the order of ten million volts. The combined energy is therefore of the order of 10,000,000,000 volts. There is additional evidence to indicate that energies of this order exist, although it cannot yet be considered a proven fact, but ener-

FIG. 19.



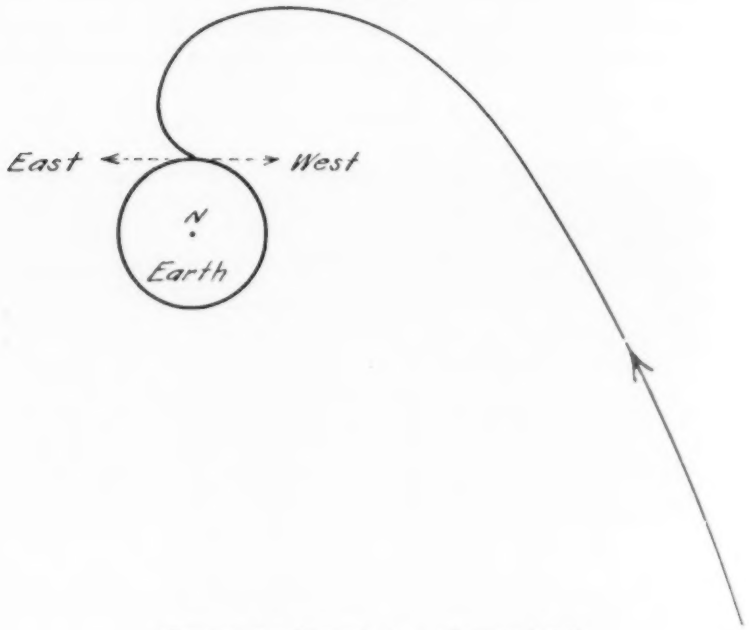
A nuclear explosion recorded by Swann and Street.

gies of this magnitude stagger the imagination in an attempt to explain their origin.

It would be impossible to conclude a discussion of the cosmic radiation without referring to the results of the expeditions of the University of Chicago and the Carnegie Institution. These expeditions headed by A. H. Compton have made intensity measurements at various stations, differing widely in latitude and elevation. The object was to determine the effect, if any, of the earth's magnetic field on the cosmic radiation, for from these results it should be possible to draw some quite definite conclusions regarding the nature of the radiations which enter from outside the atmosphere.

Electrically charged particles are, of course, deflected in a magnetic field, and if one considers, for example, a ray projected towards the earth in the plane of the equator, unless it has a sufficient amount of energy, it would be curved back on itself and would be unable to reach the surface of the earth. A ray which would be unable to reach the earth at the equator might however succeed at the poles, for there the ray is traveling more nearly parallel to the lines of magnetic force. On

FIG. 20.



The path of an electron in the earth's magnetic field.

this basis one might expect that if the rays are electrons having energies of the order of one to ten billion volts there would be a considerable difference in the intensity of these rays at different latitudes. Millikan failed to find such an effect, but in a more extensive search, Compton reports a positive result. If Compton is right it must be concluded that the primary rays are electrical in nature, whereas if Millikan is right the primary rays must be of the nature of gamma rays or possibly another form of neutral ray.

By means of the directional telescope which has been described it is also possible to determine whether or not the rays are electrically charged. In fact this method allows us to go still further and determine whether the charges are positive or negative. From the theoretical standpoint, considering a negatively charged electron of energy slightly less than 15 billion volts projected in the plane of the equator, if it reaches the earth its path must be similar to that shown in Fig. 20, entering from the east. If the ray were positive its path would be the mirror image of that shown and would enter the earth from the west. It is impossible for a negative ray of energy less than 15 billion volts to arrive at the equator from any direction west of the meridianal plane or for a positive ray of the same energy to arrive from the east. If the energies of the cosmic rays are of this order of magnitude one therefore expects to find a minimum of intensity in the east, or in the west, depending upon whether the rays are positive or negative. Making observations from the roof of the Bartol Laboratory, Street and the writer found equal intensities in the east and the west. Considering this result in conjunction with the findings of Compton the conclusion is that the energies of the rays are somewhat above the limiting value at which either azimuth is excluded. If this is the explanation a difference might still be expected to appear between the east and west intensities if observations were made at a higher elevation where the softer rays are more abundant. Measurements made by us on the summit of Mt. Washington definitely indicated a difference in the intensities in the east and west azimuths with the east a few per cent. less intense than the west. The indication therefore is, that the cosmic rays are positively charged.

An Improved Nail.—(United States Department of Agriculture, No. 747.) The Forest Products Laboratory has developed a new kind of nail which holds boxes together at the joints much better than ordinary nails. Ordinary nails undergo a chemical treatment that causes minute pitting in their surfaces and results in increased frictional contact with the wood fibers. Nails treated in this way are two to three times stronger in holding power than untreated nails.

C.

Cryogenic Laboratories.—(Science Service.) A new cryogenic or low temperature laboratory is now under construction at the California Institute of Technology. Its output is expected to be about five liters of liquid hydrogen an hour at a cost of two dollars per liter. This capacity may be compared to the plant in Berlin, the largest in the world, which can produce twenty liters an hour.

PROFESSOR A. GOETZ, who is responsible for the Pasadena low temperature work, points out that guarding against explosions is the first consideration in the design of these cryogenic laboratories. Operating at very high pressures, it is almost impossible to prevent some leakage and if the operators are not careful hydrogen, constantly evaporating from the liquid containers, will collect in the topmost corners and recesses of the room or building. Hydrogen requires particular precautions since as little as 6 per cent. mixed with air produces a violently explosive mixture that can tear a closed building to bits.

In the cryogenic laboratory of Cambridge, England, miners' safety lamps of the type invented by Sir Humphrey Davey are installed in corners of the ceiling where hydrogen is most likely to collect. When 1 per cent. of this gas collects these lamps give a signal which automatically throws open all doors and windows. In the German Physikalische Technische Reichsanstalt, which corresponds to the U. S. Bureau of Standards at Washington, the cryogenic laboratory has a very light roof merely resting over the building. In case of an explosion this roof would be blown off before a high pressure could be built up. At the Pasadena laboratory the room in which the hydrogen is liquefied has no sharp corners and the ceiling slopes upward toward the window which runs from floor to ceiling and is almost half as wide as the room. This window is to be kept open at all times of the year.

C.

ELASTIC PROPERTIES OF VARIOUS MATERIALS AND THEIR EFFECT ON THE TRANSMISSION OF VIBRATIONS.

BY

B. E. EISENHOUR AND F. G. TYZZER,

Riverbank Laboratories, Geneva, Illinois.

The design of elastic supports for machinery to reduce the transmission of vibrations to supporting structures is receiving a great deal of attention from architects, mechanical, and acoustical engineers. It is often necessary to install machinery of various kinds in office, apartment and other buildings where it is desirable that the transmission of vibrations to the structure be reduced to a minimum. If vibration isolation, as it is sometimes called, is not used on the machines, serious and annoying vibrations, perhaps not noticeable at the source, may appear at some distant part of the structure where they are amplified by resonant conditions.

It is apparent that the most effective means of preventing undue noise and vibration is to eliminate it at the source, either by correcting unbalance in rotating machinery, or by the proper design of motors and transformers so that magnetic vibrations are minimized. In many cases, however, this is impossible as in reciprocating machinery, and in other cases it is impracticable.

In reviewing the literature on the subject of reducing the transmission of machinery vibration it was found that many confusing reports on the effectiveness of flexible mountings have been published even though the basic theory is well known. In most of the experimental work published, vibrograms are presented showing the exciting motion and the motion transmitted through the material under test. The manner in which the load was applied and the use of a limited range of test frequencies to obtain an average vibration isolation make the results difficult to apply to practical cases. For example, in one instance, vibrograms are given using an apparatus consisting of two elastic systems separated by the

material to be tested. The exciting system is forced into vibration by a variable speed motor with an unbalanced flywheel and the vibration is transmitted through a test pad to one end of the beam system carrying the load. In mechanical systems of this kind the test pad is not subjected to a direct inertia load and it is difficult to compute the effect of a combination of spring and inertia loading. Unless this effect is taken into consideration a serious error may be introduced into the results. Another difficulty in interpreting many of these tests is that the results presented do not take into account the position of the resonant peak in the transmission curve of the test pads. Even if pads of the same dimensions are used, the average transmission reduction in a limited frequency range will not indicate the relative merits of the various materials.

It is believed that a better comparison of the effectiveness of materials used as flexible supports can be made from a measurement of their stiffness under a wide range of loads. The performance of any given mounting can then be calculated knowing the exciting frequency, load, and dimensions of the mounting.

A brief review of the equations necessary follows:

If a mass M mounted on a spring having a stiffness $S = 1/C$ and a resistance r proportional to velocity is acted on by a sinusoidal force F_1 having a frequency $f_1 = 2\pi\omega_1$ the force F_2 transmitted by the spring is given by Equation (1),

$$F_2 = F_1 \sqrt{\frac{r^2 + \left(\frac{1}{\omega_1 C}\right)^2}{r^2 + \left(\omega_1 M - \frac{1}{\omega_1 C}\right)^2}}. \qquad (1)$$

The transmission ϵ is the ratio of F_2 to F_1 and is given by Equation (2) where $k = r/2M$ and $f_0 = 1/2\pi\sqrt{MC}$ is the natural frequency of the system:

$$\epsilon = \frac{F_2}{F_1} \sqrt{\frac{\frac{k^2 f_1^2}{\pi^2 f_0^4} + 1}{\frac{k f_1^2}{\pi f_0^4} + \left(\frac{f_1^2}{f_0^2} - 1\right)^2}}. \qquad (2)$$

If $k = 0$ Equation (3) is obtained:

$$\epsilon = \frac{1}{\frac{f_1^2}{f_0^2} - 1}. \qquad (3)$$

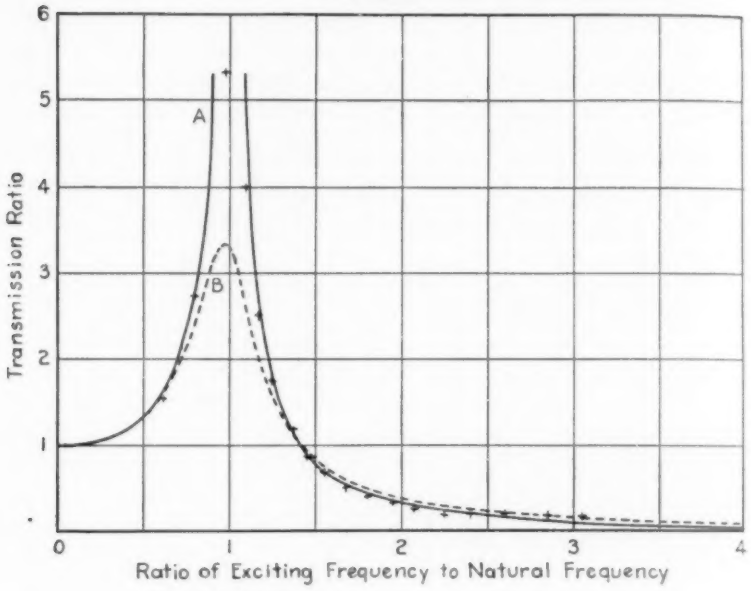
From this equation it is seen that when $f_1^2 \gg f_0^2$ and k is small, the transmission varies approximately as the square of the ratio of the natural frequency of the system to the exciting frequency.

In most practical cases the approximation made by equating the damping coefficient to zero does not lead to serious error. A large damping coefficient is advantageous if the machine is frequently started and stopped as it will prevent excessive oscillations while passing through the natural frequency. At frequencies greater than 1.4 times the natural frequency, damping increases the transmission, but the difference between a zero damping coefficient and the damping coefficients found in the various materials used in practice has little effect upon the transmission at high frequencies.

Figure 1 illustrates the variation of transmission with exciting frequency calculated from Eq. (2). In Curve A, $k = 0$, and in Curve B, $k = 1.0$. Amplitude transmission tests were made on the apparatus shown in Fig. 2, in which the load W on the spring S was supported by an iron plate A which was vibrated vertically by means of the toggle device B, eccentric C, and variable speed motor D. The amplitude of the vibrations of the exciting plate A under the spring and of the load W which it supported were measured by the motion of two light beams from the mirrors E and E_1 projected on the screen F at a distance to give an amplification of 700 to 1. The double amplitude of plate A was maintained approximately constant at .005″, and the frequency varied from 4 to 48 cycles per second.

The ordinates for the observed points in Fig. 1 represent amplitude-transmission, or the ratio of the load amplitude to the exciting amplitude, and the abscissæ, ratios of exciting frequency to the natural frequency of 2″ light density cork at a load of 55.5 lbs. per sq. in. The equation for amplitude transmission in this case is the same as Eq. (2) representing

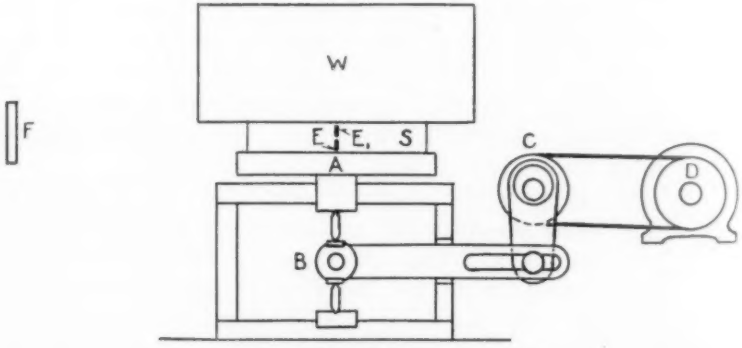
FIG. 1.



Transmission curves.
A, Theoretical Curve $K = 0$.
B, Theoretical Curve $K = 1$.
Observed points represent 2″ cork at 55.5 lbs. per sq. in.

force-transmission. The motion of the plate *A* was not sinusoidal as peaks occurred in the transmission at frequencies of one-half and one-third of the natural frequency indicating

FIG. 2.



Apparatus for transmission measurements.

the presence of harmonics with small amplitude in the motion of the exciter.

Inspection of the curves shows that a support having a natural frequency higher than the frequency of the exciting force causes the transmission ratio to be greater than one, and is therefore less efficient than a rigid mounting. A large transmission reduction is obtained by a support having a natural frequency much lower than the exciting force. In addition to steel springs a large number of materials have been used for vibration isolation. A representative list should include rubber of various densities, natural and compressed cork, felts, gelatinous materials, fiber board, etc.

Almost any elastic material will be effective in reducing the transmission of vibration in the audible range of frequencies, but a support must be designed with care to be effective at low frequencies. In some cases where exciting forces of very low frequency are encountered, the necessary flexibility of the mounting is more objectionable than the transmitted vibrations.

The frequency f_0 of a mass M on a support having a flexibility C or stiffness $S = 1/C$ and a negligible damping coefficient is given in Eq. (4):

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{MC}}. \tag{4}$$

The flexibility of a spring is equal to the deflection per unit load. When this is substituted in Eq. (4) it reduces to $f_0 = 1/2\pi\sqrt{D}$ where D is the deflection produced by the load W. If pound-foot units are used, Eqs. (5) and (6) are obtained:

$$f_0 = \frac{.919}{\sqrt{MC}}, \tag{5}$$

$$f_0 = \frac{.919}{\sqrt{D}}. \tag{6}$$

When pads of compressible material are used Eq. (7) is obtained by introducing thickness, pressure and stiffness, or Young's modulus into Eq. (4):

$$f_0 = 3.13\sqrt{\frac{E}{PT}}, \tag{7}$$

where E is Young's modulus, P is the pressure in lbs. per sq. in. and T is the thickness in inches.

In the application of the above formulas it must be emphasized that the stiffness factor E or S can be obtained from the static deflection under load only in cases where Hooke's Law applies. While the determination of the stiffness factor from the static deflection is approximately correct for helical springs, for most materials this factor varies with load and amplitude and has a decided time lag. If the stiffness of cork, for example, is calculated from the per cent. deflection for a given load, and the result used to determine the natural frequency, the latter will in many cases be as small as one-fourth of its true value. This method of determining the stiffness of cork and other materials has led to large errors in engineering data issued by the manufacturers of materials for vibration isolation.

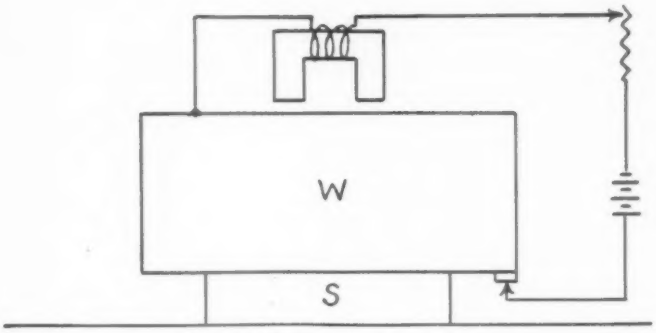
Another example of the variation of stiffness with amplitude is a multiple leaf elliptic spring. In tests on such a spring designed for a load of 12,000 lbs. the stiffness for large amplitude variations was 35,000 lbs. per ft., while that for small amplitudes was 350,000 lbs. per ft., the latter being measured from the deflections caused by small increments of load. In other words, there was little slipping between adjacent leaves for small amplitudes.

In the investigations of stiffness coefficients which this paper covers, measurements of the natural frequencies parallel to the vertical axis of a number of materials with inertia loads ranging from 0.7 to 200 pounds per square inch were made and the stiffness coefficients were calculated from the pressure, thickness, and natural frequency. In this manner a stiffness coefficient is obtained which might be called a vibratory Young's modulus as distinguished from the static value obtained from the deflection under load. This value obtained from the natural frequency varies slightly with amplitude, but can be applied without much error to calculations of transmission.

A direct load was placed on the isolating pad under test and vibrations at the natural frequency were maintained by an electro-magnet. The current in the magnet was interrupted by the motion of the load by means of a contact

attached to it. Figure 3 shows the main points of the system.

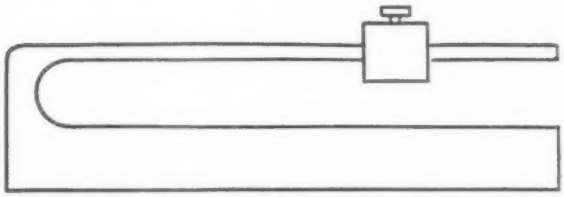
FIG. 3.



Method of electromagnetic excitation.

The determination of inaudible frequencies ranging upwards from four cycles a second was made by a visual method. A vibrating reed device was developed (see Fig. 4) by means of

FIG. 4.



Device for measuring low frequencies.

which the frequency of the vibrations could be measured. The instrument was calibrated from 4 to 32 D.V. in steps of 1 D.V. by the use of two adjustable weights. By placing the instrument on the vibrating load and setting the weight for maximum amplitude, rapid and accurate frequency determinations were possible. The sensitivity of the device was quite high, as vibrations of the exciting system having an amplitude of .0001″ gave distinctly visible amplitudes of the reed. A more accurate determination of the frequency could be made by setting the weight at the nearest integral number of vibrations per second and timing with a stop watch the

visual fluctuations or beats. This was possible as beats persisted for a long time due to the low damping in the reed device.

In any apparatus used to determine the stiffness of a material by measuring its natural frequency, it is desirable to have a rigid base as a support for the test pieces, or the lack of rigidity will tend to make the observed natural frequencies lower than their true values. It was found practical to sacrifice rigidity to some extent to greater ease in changing samples, as the error due to the slight flexibility of the base could be calculated. For approximating the effect of the flexibility of the base, it was assumed that the whole system could be represented by a mass and two springs in series. It can be shown that

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{1}{M(C_0 + C_2)}}, \tag{8}$$

where f_1 is the natural frequency of the whole system and C_0 and C_2 are respectively the flexibilities of the pad under test and the base. If f_0 and f_2 are the frequencies of the pad and the base respectively under load M, then

$$f_0^2 = \frac{1}{\frac{1}{f_1^2} - \frac{1}{f_2^2}}. \tag{9}$$

If the frequencies using pads of two or more thicknesses of the same material are measured, f_2 can be determined. A number of tests were made to determine f_2 and the close agreement between observed values was taken to indicate that the method of correction was valid. For a load of 2000 lbs. f_2 was equal to 42.7 D.V., giving a flexibility coefficient of $.224 \times 10^{-6}$ ft. per lb. The accuracy of the correction factor thus determined was found to be quite sufficient if the thickness of the test pads was such that their flexibility was not less than this value.

For the lighter loads a block of stone $2' \times 2' \times 2'$ mounted firmly on a cement slab was used as a base. Investigation showed that no correction was necessary for this mounting within the range tested.

The maximum load available was 3000 lbs. Test pieces

12″ × 12″ were used up to 21 lbs. per sq. in. and higher pressures were obtained by reducing the area of the test pieces.

It might be expected that large areas of material compressed between two flat surfaces would be stiffer than a number of small pieces of equal total area but not in contact laterally, since, in the case of the large areas, the material in the interior experiences considerable lateral constraint. Experiments were made on each material to determine if the necessary reduction in area for the heavier loads caused a measurable change in the stiffness coefficient. In the case of rubber and like materials the change in the stiffness coefficient for a variation in area was quite marked, but for cork and felt it was very small if the thickness did not greatly exceed the width or breadth. In the latter case it is difficult to apply the load equally over the area and a shearing effect is produced.

In one test the frequency of a 12″ × 12″ × 12″ piece of light density compressed cork 1 lb. per bd. ft. under load of 2000 lbs. was measured and then compared with the frequency using the same sample cut into 64 pieces which were separated by 1/16″ spaces. Taking into account the area reduction due to the sawcuts, the frequencies checked to within 2 per cent.

Tests on natural cork show that the restraining effect of the narrow iron band used to hold together built up areas causes no measurable change in the stiffness.

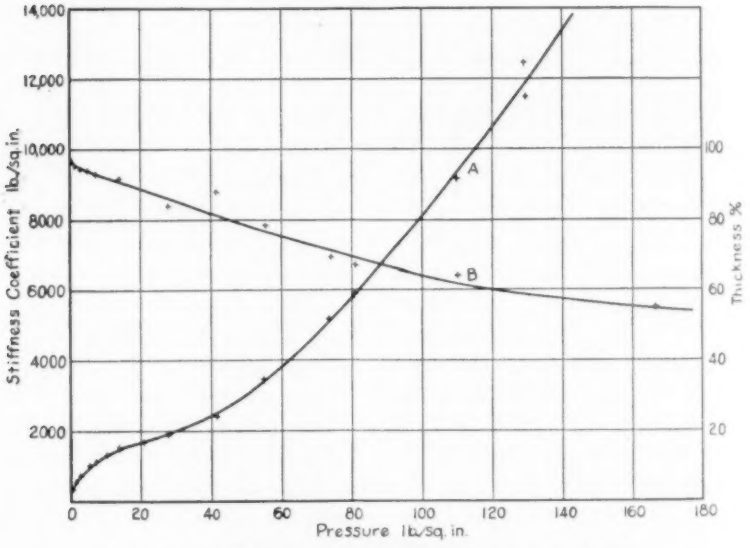
In order to determine whether a lateral expansion could be detected in small areas of cork under load, four cylinders of compressed cork 1.5 lbs. per bd. ft., $3\frac{1}{2}''$ in diameter and $2\frac{13}{16}''$ high, were fitted closely into brass tubes $2\frac{1}{16}''$ long, and having walls 1/8″ thick, and the torque necessary to rotate them measured. For a load of 2000 lbs. on the four cylinders corresponding to a pressure of 51.4 lbs. per sq. in., the cork decreased 24 per cent. in height, but no increase in the torque necessary to rotate the tubes could be measured, indicating practically no lateral expansion for this large change in volume.

In working with materials like cork a change in frequency and therefore in stiffness can be observed for a considerable

time after the load was applied. The rate of change of stiffness decreases with time and becomes very small 12 to 24 hours after the application of the load. The recovery after the removal of the load is also a function of time. All test pieces were pre-loaded for twenty-four to forty-eight hours for each load before the frequencies were measured.

The values of the stiffness coefficient $E = 1.02PTf^2$ shown in the curves referred to below were calculated from the original thickness instead of the thickness under load. From these curves it is possible to calculate the natural frequency of a mounting from the load and original dimensions without referring to a deflection curve.

FIG. 5.



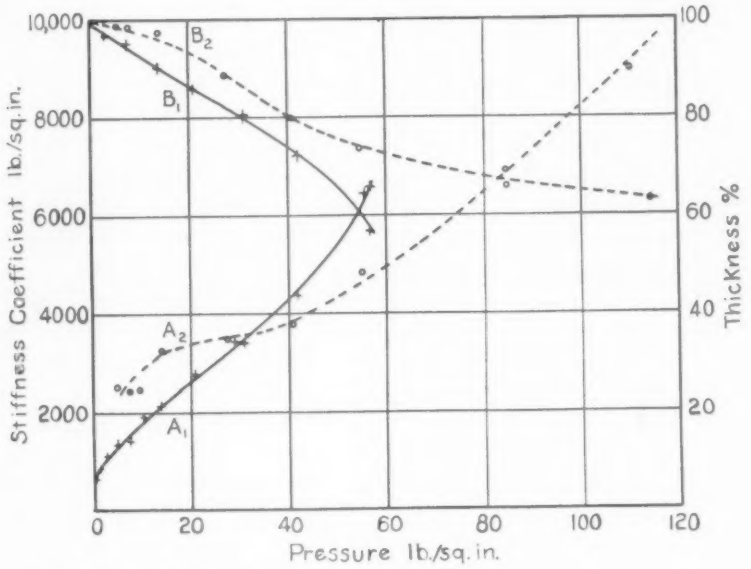
Variation of stiffness and thickness with pressure for natural cork.
A, stiffness coefficient.
B, thickness.

The results of the tests made on various grades of cork are shown in Figs. 5 and 6. In Fig. 5, the stiffness coefficient is plotted against pressure in Curve *A*, and the thickness under load is shown in Curve *B*, for natural cork test pads. The variation between samples of natural cork is quite large—and the points on the curve represent average values.

The curves marked A_1 and A_2 in Fig. 6 show similar results for compressed cork of light and heavy densities, 1 and 1.66 lbs. per bd. ft. respectively, and the curves marked B_1 and B_2 show the thickness under load.

If the stiffness coefficient is calculated from the deflection under load and the immediate recovery, it will be much smaller than the value calculated from the frequency. For

FIG. 6.



Variation of stiffness and thickness with pressure for cork:
A_1, stiffness of light density cork.
B_1, thickness of light density cork.
A_2, stiffness of heavy density cork.
B_2, thickness of heavy density cork.

example, light density cork at 25 lbs. per sq. in. (referring to Fig. 6, Curve A_1) has a stiffness factor of 3000 lbs. per sq. in., but Curve B_1 shows the thickness under load to be 83.5 per cent., while the thickness immediately after removal of the load was 87.0 per cent. of the original thickness, giving $E = 25 \times 100/87 - 83.5 = 715$ lbs. per sq. in.

In the case of light density cork the deflection load curve (Fig. 6, Curve B_1) turns sharply downward in the neighborhood of 55 lbs. per sq. in., and the stiffness increases rapidly.

At these loads noticeable lateral expansion occurred and small particles of cork became detached from the sides of the pad. It is believed that the small size of the test pieces tended to reduce the load at which this occurred. Except in this case it is our opinion that the use of small test pieces did not cause much error in the results, as explained previously.

The difference in the stiffness coefficients of the various densities of compressed cork was not large except for light loads. Several specimens of medium density cork 1.50 lbs. per bd. ft. had a greater stiffness coefficient than the heavy density 1.66 lbs. per bd. ft. supplied by the same manufacturer. There was, however, considerable difference in the deflection under load, and the pressure at which evidence of failure was observed was less for the natural and light density cork. All of the cork test pieces showed an increase of stiffness coefficient with increasing load, the rate of increase becoming larger at heavy loads.

If the equation $f = 3.13\sqrt{E/PT}$ is differentiated with respect to P and df/dp equated to zero, it is seen that, as P is increased, a minimum frequency is reached when $dE/dP = E/P$.

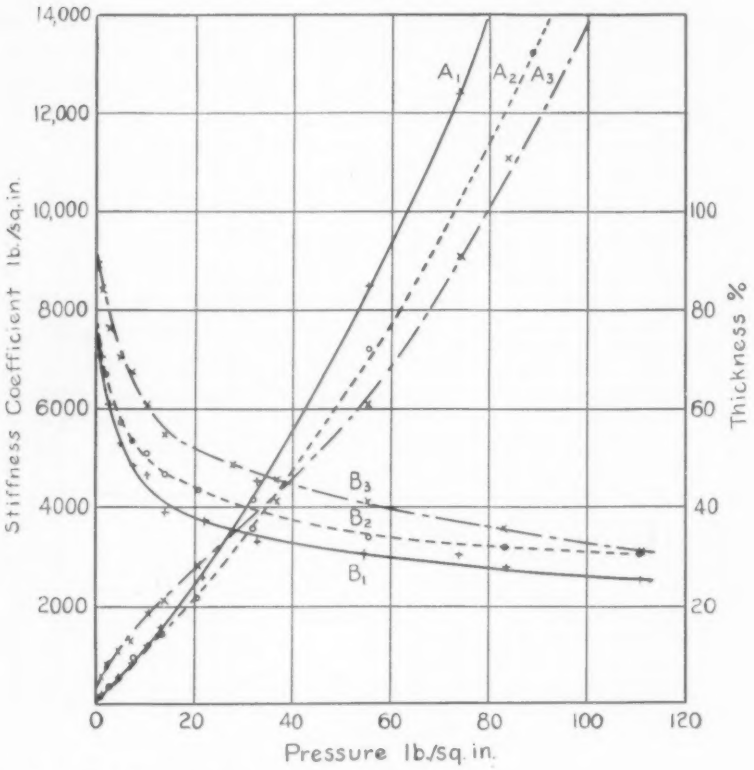
If $dE/dP < E/P$ the frequency decreases with increasing load. If $dE/dP > E/P$ the frequency increases with increasing load. If $dE/dP = E/P$, the frequency is constant and the stiffness-load curve is a straight line passing through the origin. There is of course no reason for increasing the pressure beyond this minimum frequency in practice, and even for pressures considerably below there is little change in frequency for increasing loads.

The curves in Fig. 7 show the variation of thickness and stiffness coefficient with load for three felt pads. Curves A_1 and B_1 represent 1″ hair felt. Curves A_2 and B_2, a wool felt, and Curves A_3 and B_3, a hair felt with included asbestos material. The use of the original thickness in calculating the stiffness coefficients for felts tends to make them appear to be much stiffer than is the case when the thickness under load is used.

In Fig. 8 the stiffness coefficient and deflection for a compressed wood-fiber board are plotted against pressure.

This material did not show any evidence of failure at 300 lbs. per sq. in. and the curves indicate that it resembles cork more than felt in its stiffness characteristics under load.

FIG. 7.

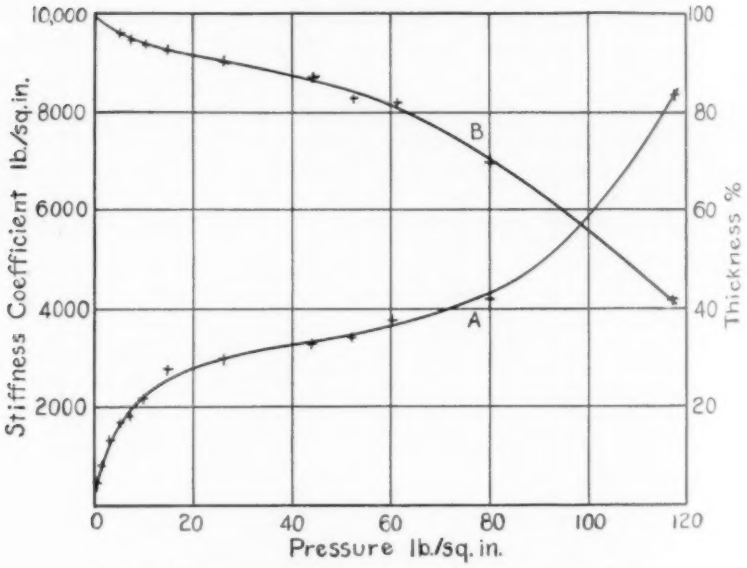


Variation of stiffness and thickness with pressure for felts.
A_1, stiffness of hair felt.
B_1, thickness of hair felt.
A_2, stiffness of wool felt.
B_2, thickness of wool felt.
A_3, stiffness of asbestos fiber felt.
B_3, thickness of asbestos fiber felt.

In tests made on rubber it is necessary to make allowance for the fact that rubber has a small modulus of rigidity compared to its bulk modulus. For example, a single large sheet of rubber between two plane surfaces will have a higher stiffness coefficient than a number of small pieces not in

lateral contact but having an equal total area. This lowering of the stiffness with decrease of lateral constraint should be taken into consideration in the application of rubber to vibration isolation. The amount of lateral constraint depends on the area and thickness of the rubber pieces. In a test made on $2\frac{3}{8}'' \times 2\frac{3}{8}''$ rubber blocks under a load of 121 lbs. per sq. in., the stiffness coefficients for different thicknesses were as follows: 5″ and 4″, 3900; 3″, 3970; 2″, 4460; and 1″, 5360 lbs. per sq. in. The change in thickness under load

FIG. 8.



Variation of stiffness and thickness with pressure for wood fiber board.

for the 5″, 4″ and 3″ blocks was about 9 per cent., and for the 2″ and 1″ blocks it was 7.7 and 4.6 respectively. The maximum lateral expansion was approximately constant at 6 per cent. for the five thicknesses, and the dimensions of the areas in contact with the loading surfaces did not change appreciably. The rubber used in these tests had a density of .0524 lb. per cu. in. The time lag in settling under load was not as pronounced as in the other materials tested, but it was not vanishingly small as is shown by the fact that the

modulus of elasticity based on the deflection at a given load is much smaller than the value based on the natural frequency for the same load.

The measurements made on rubber were not complete enough to formulate the relation of the stiffness of rubber to its dimensions. In the paper "Elastic Supports for Rotating Machinery," by E. H. Hull and W. C. Stewart, curves are given illustrating this relation for 1" thick rubber.

The shapes of the stiffness curves of the various materials are very different. In the case of cork the rate of increase of stiffness with pressure increases with load except for light loads. It is believed that this reversal in curvature is caused by surface irregularities in the cork which cause at light loads a reduction in effective area and therefore in apparent stiffness. The wood-fiber board showed a similar effect. The stiffness of felt is approximately proportional to the pressure until heavy loads are reached. Since the lightest load tested caused a deformation of 10 to 20 per cent., no decrease of contact area such as occurred in cork was present.

Although the relative efficiency of the materials tested can be determined from the curves presented, a more direct comparison is made in Table 1, which shows the natural frequency of a number of materials based on a thickness of one inch under load. The natural frequency for any thickness can be calculated by multiplying the frequency in the table by one over the square root of the thickness. The thickness under load was used in the table as it gives a better comparison of the materials under operating conditions. The table includes several materials not shown in the curves. As a basis of comparison the frequencies of a system having a constant stiffness are tabulated in the column headed helical spring. If the pressures in the first column are taken as load in hundreds of pounds, the spring would have a stiffness of 1.24×10^6 lbs. per ft. In several cases in the table increasing the pressure increases the frequency as $dE/dP > E/P$.

By varying the dimensions and location of the isolating materials the six natural frequencies of translation and rotation may often be adjusted to suit the conditions of operation. For example, it may be desired to withstand a horizontal belt pull and yet keep the vertical frequency of

TABLE I.

Pressure lb/sq. in	Helical Spring	Natural Cork	Comp Cork (Light)	Comp Cork (Medium)	Comp Cork (Heavy)	Wood Fiber Board	Hair Felt	Asbestos Felt	Wool Felt	Jute Felt	Gelatinous Compound	Gelatinous Compound Sponge
1	100.0	73.5	82.9	99.0		61.0	31.2	56.0	32.8	35.7		35.4
2	70.7	68.1	65.2	78.1		50.5	28.8	48.5	27.1	31.3		29.6
3	57.7	63.3	57.8	68.4		47.2	27.2	45.1	26.0	30.3		26.8
4	50.0	59.0	53.4	62.6		44.3	25.7	41.3	25.2	30.0		25.7
5	44.7	54.3	49.5	57.9	63.2	42.0	24.2	38.3	24.5	30.0		25.0
6	40.8	51.6	46.7	54.8	60.0	40.0	23.3	36.0	24.1	30.0		24.2
8	35.4	46.9	43.0	49.5	54.5	37.2	22.4	32.8	23.4	30.4		22.9
10	31.6	43.7	40.4	45.9	51.0	34.8	22.0	30.8	22.8	30.3		22.6
15	25.8	38.9	36.1	40.5	43.9	31.1	21.5	27.5	22.1	30.6	29.2	21.8
20	22.4	34.8	33.3	36.1	38.5	27.6	21.0	25.7	21.9	29.9	28.0	
30	18.2	29.4	29.6	30.3	31.8	23.7	21.1	23.4	21.8	27.2	26.8	
40	15.8	26.1	27.6	27.4	27.8	22.6	21.1	22.2	21.2	26.6	25.4	
50	14.1	23.7	26.0	25.7	26.2	21.9	21.4	21.3	20.8	25.8	24.2	
60	12.9	21.8	25.1	24.4	25.9	21.9	21.5	20.8	21.0	25.2	22.8	
70	11.9	20.7	24.4	23.9	25.2	21.8	22.0	20.5	21.6	25.4	21.6	
80	11.2	19.6		23.8	25.1	21.7	22.6	20.4	22.2		20.9	
90	10.5	18.6		23.7	24.9	22.0	23.2	20.6	23.2		20.6	
100	10.0	17.8		23.5	24.8	22.3	23.6	20.8	24.5		21.0	
125	9.0					22.5	25.0	21.3				
150	8.2					22.7		22.6				
200	7.1					23.1						
250	6.3					23.8						

Natural frequencies of materials 1" thick under load.

the machine low. If a machine mounted on springs is bolted down and restraining springs are used under the bolt heads, little change in frequency is produced by varying the compression of the springs, as a good helical spring has a constant stiffness for a considerable range of load. When materials are used in which the stiffness coefficient increases with pressure, the natural frequency of the system will depend to a large extent on the restraining force exerted by the bolt heads. The stiffness of a system consisting of a mass restrained between two elastic systems is equal to the sum of the stiffnesses of the two systems at their respective loads.

In the actual installation work, the observed frequency of a machine on its supports may be slightly lower than that calculated from the values given in the table, as the flexibility of the foundation under the isolating mounting must be taken into consideration.

In considering the effect of the support beneath the isolating mounting for a machine it should be emphasized that the effectiveness of any mounting will be greatly reduced if the machine is located on a beam or other structural member having a natural frequency coinciding with or near the exciting frequency of the machine. In this case the two frequencies must be separated; either the frequency of the beam must be decreased by loading, or increased by external stiffening until it is not in resonance with the exciting force.

Although the choice of materials for isolating mountings will in some cases be limited by surrounding conditions, such as high or low temperatures, the presence of water, acids, or oil, the elastic coefficients given in the foregoing curves, when properly used, should facilitate the calculation of the natural frequency of a machine mounting using the materials listed.

REFERENCES.

HULL, E. H., STEWART, W. C. A.I.E.E. Trans., Vol. 50, May, 1931, p. 347.
KNUDSEN, VERN O. Architectural Acoustics, John Wiley & Sons, Inc.
SLOCUM, STEPHEN, E. Noise and Vibration Engineering, D. Van Nostrand Co
SODERBURG, C. R. Elec. Jour., Vol. XXI, No. 4, 1924, p. 161.
TIMOSHENKO, S. Vibration Problems in Engineering. D. Van Nostrand Co.

A Huge Diesel Engine.—One is apt to consider engineers as individuals not particularly impressionable. However, nonmembers of this fraternity hardly could escape being awestruck by the appearance of the world's largest diesel engine. According to Science Service, this internal combustion prime mover has an overall length of almost 65 feet and a height of about 35 feet. Its eight cylinders are comparable in size with an automobile, each being nearly a yard in diameter with a piston travel of almost five feet. This crude oil burning engine is rated at 22,500 brake-horsepower and is to drive a 15,000 kilowatt generator. Its builders claim that a large diesel-powered generator can be built more cheaply than a corresponding turbine and boiler plant and have put forward plans for the construction of a 30,000 kilowatt generator to be run by a 40,000 brake-horsepower diesel. Crude oil is injected into the cylinders of this new engine at pressures as great as 6,000 pounds per square inch. Its speed is 115 revolutions per minute while that of the proposed larger engine would be 187.

C.

The Inter-Society Color Council.—This recent organization has issued its first Bulletin for the purpose of acquainting the members with its activities. The dominating purpose of this Color Council from the very first thought of its inception has been to provide a means for standardizing color names and of providing uniform methods for designating or specifying colors. A second function of the Council will be to serve as a clearing house for definite color problems. As an illustration of these problems one might mention the well-known poison label used by druggists and others handling poisons. This label is printed with red letters on a white background as is prescribed by law. The question has arisen as to which color of red or orange is most desirable for this label, from the standpoint of those who are more or less color blind.

The progress report of the Committee on Measurement and Specification is rather extensive and consists for the greater part of an account of the action taken on the problem submitted by the U. S. Pharmacopœia. The latter requests a means of designating colors in a way sufficiently standardized as to be acceptable to science, sufficiently broad to be appreciated and usable by science, art and industry and sufficiently commonplace to be understood, at least in a general way, by the whole public. A Committee on Color Names also has been at work and its report describes the results of a survey of the present status of color names.

C.

A DIRECT CURRENT BUSHING TRANSFORMER.

BY

ALAN S. FITZGERALD.

INTRODUCTION.

It is an interesting and stimulating occupation occasionally to give ourselves a brief respite from those pressing and immediate problems in electrical engineering, with which we are in daily contact, and to contemplate for a few minutes future tendencies and probabilities; to consider, sometimes, one or two of the problems we are likely to be faced with a few years from now, and the lines along which we may expect to find their solution.

Recent developments in hot cathode mercury vapor tubes definitely foreshadow active investigation of the possibilities of transmitting large amounts of power by means of direct currents at high voltages, up to, and possibly exceeding, 100 Kv. In addition to the prospect of economic gains in line insulation and construction many of the more complex problems associated with alternating current power transmission, as for instance, questions of line inductance, line capacity, stability, and telephone interference, would seem to present entirely different aspects which promise more effective solution.

Many important features of electron tube design and construction will have to be worked out, and many major problems in the handling and control of large amounts of high voltage direct current power will engage the attention of central station engineers. The possibilities of tube control circuits are so extensive that we may confidently anticipate the successful solution of these problems in due course of time.

The present paper deals with the question of how we are going to ascertain the magnitude of direct currents flowing in transmission lines and other circuits at high potential. This may seem to be one of the lesser problems involved, perhaps,

because we are so accustomed to the simplicity of the A.C. current transformer or bushing transformer circuits that we do not realize what an important function they perform. The late Lord Kelvin made the well-known statement that until he was able to measure anything he did not feel that true knowledge of it was possible, or words to that effect. This was never more true than in the case of power transmission and control circuits. Without an exact knowledge of the conditions in high voltage circuits it would be impossible properly to handle and control the power.

In alternating current systems the bushing transformer is an inexpensive device which may be incorporated in a high voltage line without involving any complicated or costly insulating or constructional problems. Nor does it represent any hazard to reliable operation of the system. It provides a secondary circuit completely insulated from the high voltage system, and a secondary current proportional to the primary current and of a value—namely 5 amperes—for which it is convenient to furnish measuring instruments. It enables standard windings to be employed irrespective of the range of the scale reading. Moreover the relation between primary and secondary currents is maintained, over a wide range, independent of the secondary impedance or burden represented by such instruments, relays, etc., as we may wish to connect in the secondary circuit.

In a direct current system, it is commonly the practice either to connect the instrument directly in the circuit or to employ shunts from which the instruments are operated. The amount of power in the shunt circuit is usually small and the length and resistance of the shunt leads are restricted. And, of course, the instrument is at the same potential as the line to which it is connected.

This arrangement becomes increasingly inconvenient as the voltage becomes higher and it is evident that for voltages in the neighborhood of 100 Kv., instruments would have to be mounted out of doors, involving difficulties in maintenance and repairs and additional costs in insulating the instrument leads for full voltage. Probably the instruments would have to be remotely observed by means of a telescope. Even if metering were restricted to the grounded line, safety pre-

cautions under short circuit conditions would demand similar arrangements. Moreover line insulation economy might indicate that neither line be operated at ground potential.

These brief considerations are sufficient to indicate that it would be a very great advantage if we could enjoy, in a high voltage D.C. transmission system, facilities comparable with those to which we have become accustomed in present day alternating current installations. We should like to have the equivalent of the A.C. current transformer. We should like to have a secondary circuit completely insulated from the primary and in which there will flow a current at all times proportional to the primary current; in which the secondary current is, within limits, independent of the secondary impedance; and in which a standard secondary current rating may be adopted for all instrument scale ranges.

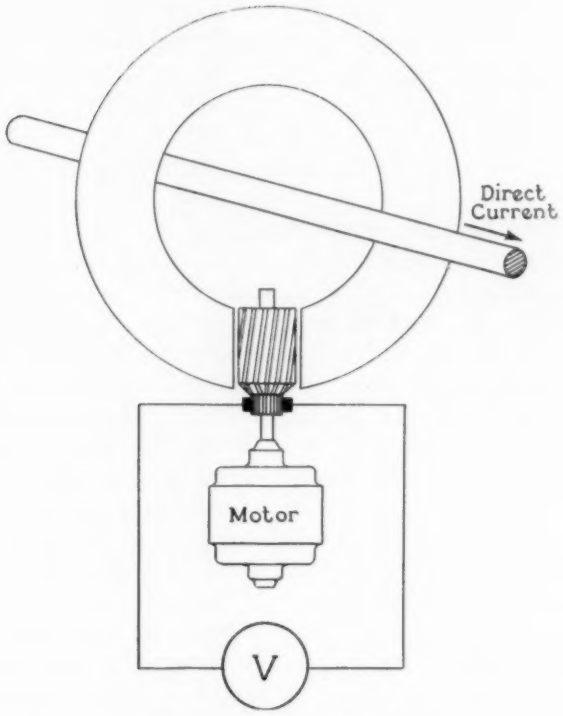
The results of the work described in this paper indicate that all of the desirable results mentioned above, are capable of accomplishment. While it is doubtful whether the cost of furnishing the equivalent of a current transformer for a D.C. circuit will not be somewhat greater than the cost of an A.C. bushing transformer and secondary circuit, it is of interest to note that so far as the high voltage circuit is concerned no structural features or insulating arrangements are required for the direct current arrangement which differ in any way from the standard A.C. bushing transformer equipment. The additional special apparatus and circuits by means of which current transformer characteristics are furnished when the primary current is direct instead of alternating, exist entirely in the secondary circuit and are not insulated for high potential. Whenever the need for such a device manifests itself to an extent that economic manufacturing quantities would be required, there is no reason to believe that the cost of the apparatus would involve any serious difficulty.

GENERAL PRINCIPLES.

It will be desirable to keep as closely as possible to the principle of the alternating current instrument transformer. There may be provided, therefore, an iron core of circular form surrounding the direct current conductor in which there

flows, at a high voltage, the current to be measured. As in the alternating current transformer, we shall try to arrive at a measurement of the primary current by means of the magnetizing effect that this primary current exerts upon the core surrounding it. The first thought that this suggests is illustrated in Fig. 1. This diagram shows the core of the

FIG. 1.



Direct excitation principle.

transformer with an air gap, in which rotates an armature driven at constant speed by a motor. The voltage generated in this armature is an indication of the magnetic flux in the core and is, therefore, an indication of the primary current.

While this scheme is theoretically sound, it has obvious practical objections. It represents, however, one principle or method of attack to which it may be convenient to refer

briefly. Namely, this is a scheme in which we attempt to measure directly an effect proportional to the primary current. Thus, any errors or discrepancies in the circuit or apparatus involved would give us accordingly a proportional inaccuracy. This is different from the principle employed in the current transformer, in which automatically the secondary current is maintained equivalent, in ampere turns, to the primary current. Within limits, differences in the magnetic circuit or in the secondary circuit impedance do not cause errors. This is because the current transformer operates essentially on a comparison or balance principle. It is desired especially to point out the advantage of a null or balance method over a direct reading method.

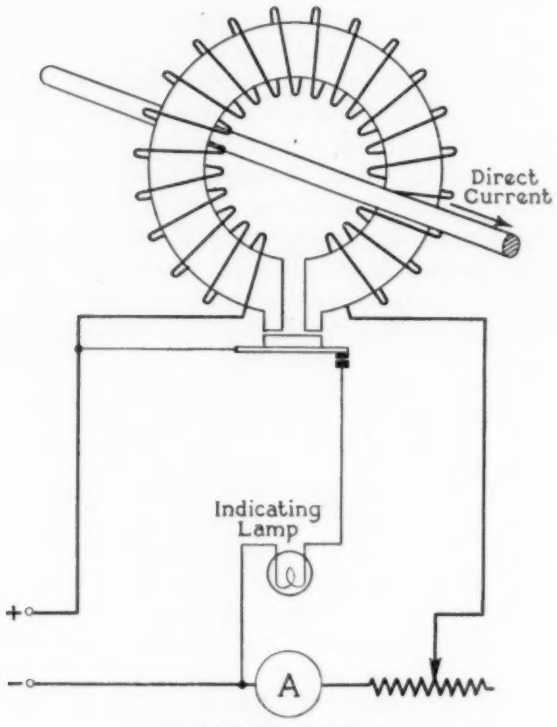
Figure 2 shows in a very elementary way the basic idea of the comparison method for direct current measurement, first described by Knopp in the *Electrical World*, October 2, 1915. The magnetic circuit is shown with an air gap, across which is arranged a light armature on which are mounted contacts; by this means it is possible to ascertain whether the core is magnetized or not. A secondary winding is provided on the magnetic circuit to carry current from a direct current source which may be adjusted by means of a rheostat. By manipulating the rheostat, it is possible to adjust the secondary current so that the magneto motive force due to the secondary current is directly equal and opposite to that due to the primary current. The point of balance will be marked by the relay dropping out; by mounting circuit opening contacts on the armature, there may be provided an indicating lamp mounted near the instrument which reads the secondary current.

Figure 3 shows a similar scheme in which moving elements and contacts on the core are avoided. There is used instead a Magnetron tube which may operate a lamp directly or by means of a relay in a similar manner.

It will be noted that in Figs. 2 and 3 the balance or comparison principle is employed, which is much more favorable to high accuracy than direct indication. Providing the detecting means are sufficiently accurate there is a direct relation between the primary and secondary current which is a function of the secondary turns exactly as in the case of the A.C.

current transformer. Variations in the supply circuit or the rheostat have no effect upon the accuracy which depends only on the precision of the flux detecting device. If the flux detecting device should change its characteristics by 20 per cent., this does not cause a 20 per cent. error in the reading but it causes the normal error to be increased by 20 per cent.,

FIG. 2.



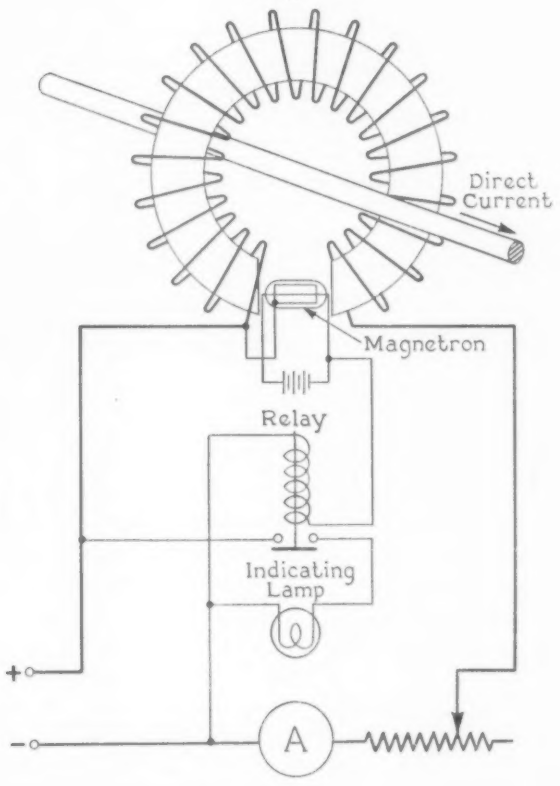
Principle of balancing method.

which is a much less serious discrepancy. Thus the balance or comparison system is clearly to be preferred for instrument operation.

Figures 2 and 3 have been included to show the possibility of the D.C. current transformer from a theoretical standpoint and to show the derivation of the schemes which follow. Both Figs. 2 and 3 have serious practical objections which largely

arise from the following condition. The most convenient type of current transformer is the bushing transformer usually installed on circuit breakers. In any case, the current transformer core, if it is to be big enough to be insulated for very high voltages, is a large and cumbersome device which is

FIG. 3.

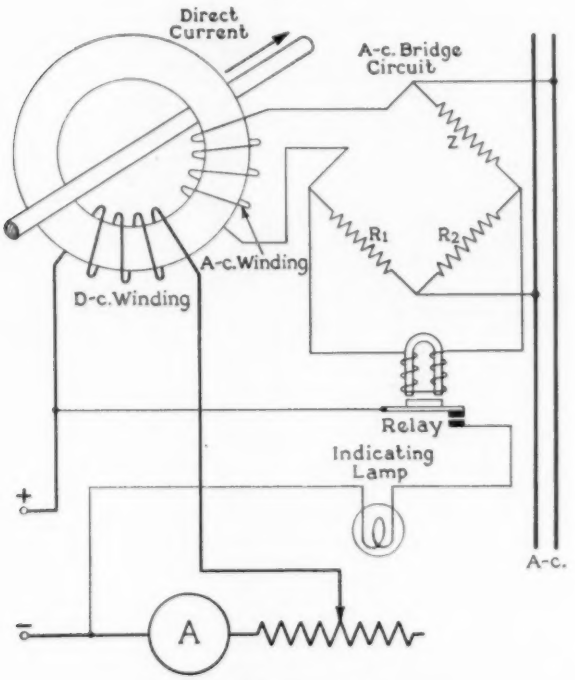


Use of Magnetron.

clumsy to handle and install. It often has to be erected by means of cranes and tackle and it would be undesirable if such a heavy device were to contain either contacts or glass tubes. Moreover, when installed in a circuit breaker or other intimate relation with a high voltage conductor, it would be unfavorably located for good maintenance. There-

fore, there has been aimed at a system adhering more closely to the ideal represented by the A.C. bushing transformer in which there is an iron core having no air gap or gadgets associated with it, and bearing nothing but a secondary winding. This core may be handled quite roughly during installation without being in any way damaged.

FIG. 4.



Saturation balance principle.

Figure 4 shows the elements of this new system of operation. Surrounding the primary conductor in which the high voltage direct current flows, is a closed iron circuit just as in an ordinary A.C. bushing transformer, except that the core may be made of permalloy or other special alloy having a high permeability at very low orders of magnetizing force. This core is furnished with two windings; one of these, which may be called the secondary winding, is arranged to carry a

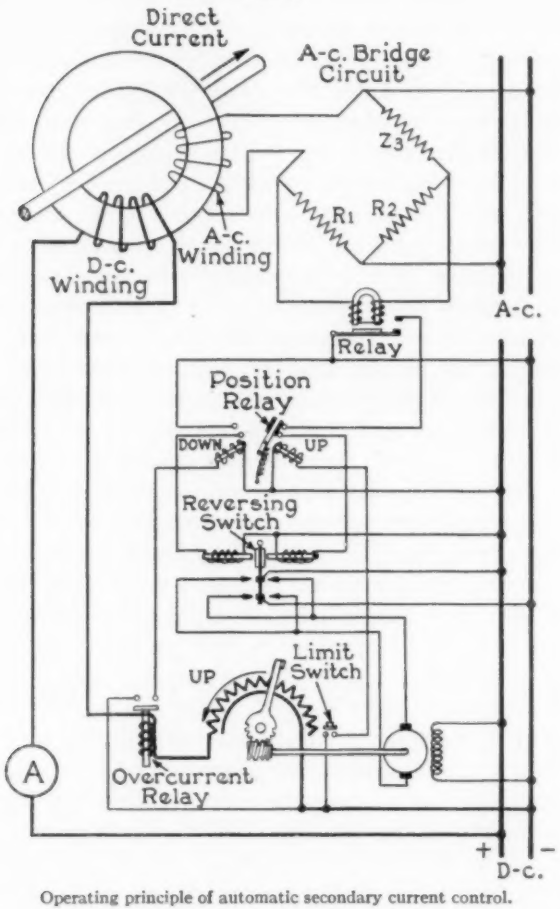
direct current equivalent in ampere turns to the primary current; the other winding, which may be called the search coil, forms one arm of a bridge circuit. This bridge consists of the said search coil, a second coil of similar characteristics to the search coil, and two resistances.

A sensitive A.C. relay is connected across the bridge as shown and the complete bridge is excited from an alternating current source. The action of the device is as follows: The relay picks up at any time when the bridge does not balance. When the bridge is exactly balanced, the relay closes its contacts and lights the lamp. The bridge is energized at a low voltage, only sufficient to excite the core of the current transformer to a relatively low flux density, at which its permeability is very high. With no direct current flowing in either the primary or the secondary windings, the bridge is exactly balanced by means of the resistances. A D.C. current of one or two amperes flowing in the primary conductor, that is, one or two ampere turns, is sufficient to change the permeability of the permalloy core to an extent such as to produce a detectable unbalancing of the bridge. Thus, when any given D.C. current flows in the primary conductor, the secondary current may be adjusted by means of the resistance until the lamp lights, when the current may be read. Clearly, the lighting of the lamp indicates that the relay has opened—showing that the bridge circuit is balanced. This means that the secondary current, adjusted by the rheostat, is substantially equal and opposite to the primary current, such that there is no appreciable direct current magnetization of the core to unbalance the bridge.

In Figure 5 is shown a complete system of connections for automatically controlling the current so as to avoid the manual performance of this operation. The development of automatic follower mechanisms for balancing any kind of bridge circuit is a familiar problem. Such devices are well known in connection with temperature measurement systems and many other applications. There is, however, a special feature of the present balanced circuit whereby it differs from the better known arrangement. It may be desirable to explain this somewhat more fully. The usual follower mechanism operates in connection with a bridge circuit which has

three operating conditions. The bridge may be balanced, it may be unbalanced in one direction, or it may be unbalanced in the other direction. Thus, the detecting device or relay receives a voltage differing in polarity, according to whether

FIG. 5.



Operating principle of automatic secondary current control.

the bridge, is above or below the balance point. The motor operated rheostat, or whatever device is arranged to balance the bridge, may be arranged to run in one direction or the other, according to whether the bridge is above or below balance, and to stop when the balance point is reached.

But, in the present scheme, a moment's consideration will show that this condition does not hold. The change in impedance of the A.C. search coil is independent of whether the difference in resultant magneto-motive force is due to the primary current being greater than the secondary, or the secondary current being greater than the primary. Therefore, when the circuit becomes unbalanced, the balance circuit does not indicate whether we ought to reduce the secondary current or to increase it, since the polarity of the difference is not known.

This difficulty may be readily overcome by several methods, one of which is illustrated in Fig. 5. In this diagram, the current in the secondary winding is controlled through a reversing contactor and a position relay, from the bridge relay. When the bridge is unbalanced, the motor runs, driving the rheostat in a direction which is controlled by the position relay. By a position relay is meant a relay which remains in the position in which it was last thrown by energizing one or other of the two operating coils. Thus, if this relay is thrown so as to operate the motor in the direction which increases the current, it remains in this position until the other operating coil is energized. Under normal operating conditions, the position relay will rest in the position which operates the motor in the direction which reduces the resistance of the rheostat and increases the secondary current. A relay operated by the secondary current is arranged to pick up at a value of current corresponding to the maximum scale reading of the ammeter, or a little above this. When this relay operates, it throws the position relay from the direction corresponding to increase of secondary current onto the opposite contacts, which causes the motor to run in the opposite direction. Since the relay is of the position type, and since the bridge relay contacts are not included in this circuit, the motor will run the rheostat to the "all in" position, when the arm will strike the limit switch which throws the position relay onto the "raise current" side. The bridge relay is now in circuit and the motor commences to run in the other direction, increasing the current until the balance point is reached, when the bridge relay opens the contacts and the motor stops. The secondary current is now exactly

equivalent in ampere turns to the primary current. Thus, when the primary current changes to a higher value, the motor is operated by the bridge relay and increases the secondary current to this value when the bridge relay opens and the motor stops at this new balance point. But, if the primary current decreases, the motor will run the rheostat up to the maximum current position, and will then instantly return to the "all in" position; it will then approach the balance point from below, and will stop when the new balance point is reached.

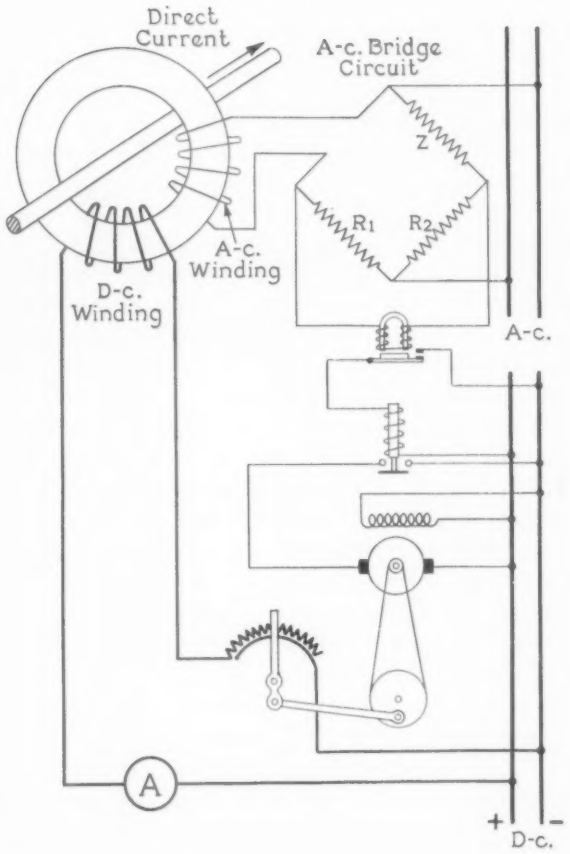
The object of including the diagram Fig. 5 is to indicate the operating principles of the automatic system and to establish clearly the sequence of operation which must be performed by the circuit. Thus it is hoped that engineers familiar with automatic control circuits will have no difficulty in following the operation of the arrangements which will now be described, in which engineering principles, which are less generally well known at the present time, are employed.

If it were desired to employ an electro-mechanical system we might use a more simple scheme than that shown in Fig. 5. This is shown in Fig. 6. According to this scheme a simple mechanical reciprocating motion is imparted to the rheostat so that this varies continuously between maximum and minimum limits as long as the motor is permitted to rotate. When the balance point of the bridge is passed through as the current in the secondary circuit either increases or decreases the relay opens and the motor stops. The secondary current then indicates the value of the current flowing in the primary conductor.

In Fig. 7 is shown an arrangement exactly similar in operating processes and in principle to the system shown in Fig. 5, but instead of using electro-mechanical apparatus we have employed vacuum tubes and Thyratron tubes so that we now carry out exactly the same operation with apparatus possessing neither contacts nor moving parts. In addition to the advantages of the elimination of these items in respect to maintenance and adjustment, we get much faster operating speed and much quicker response, so that, in effect, the control circuit will establish a new balance point so rapidly that the ammeter will not follow the complete scanning of the scale which the system in principle carries out.

The operation of the D.C. current transformer shown in Fig. 7 is as follows. The core, with its windings, and the bridge circuit, remain the same as in Figs. 4 and 5. Any appreciable magnetization of the core, due to a difference in

FIG. 6.



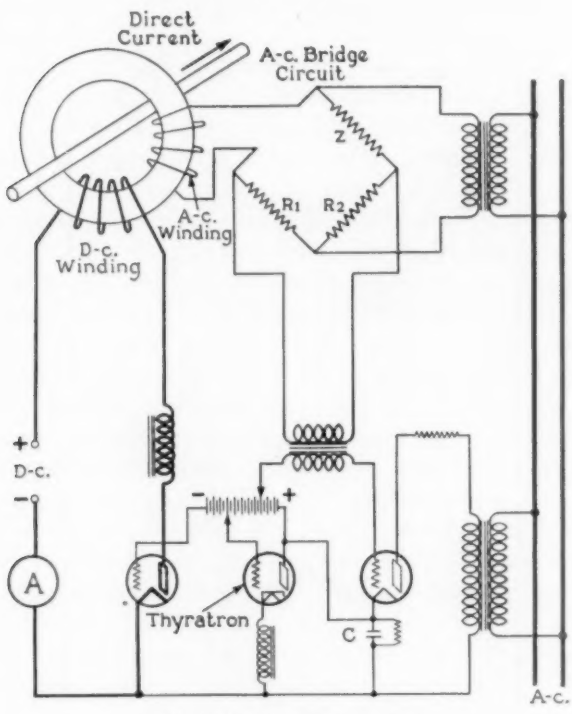
Simple automatic operation.

ampere-turns between the primary and secondary windings, will cause the impedance of the search coil to decrease, thus unbalancing the bridge circuit. The out-of-balance voltage from the bridge is impressed on the grid of the detector tube

and causes the tube to conduct. The tube is normally biased to cut-off. This detector tube corresponds in function to the sensitive relay shown in Figs. 4 and 5.

The plate current of the detector tube, when the bridge becomes unbalanced, charges the condenser *C*. The voltage held by *C* is applied to the grid of the secondary tube and thus

FIG. 7.



Principle of electron tube system.

regulates the current in the secondary winding of the bushing transformer. As long as the bridge is unbalanced the detector tube continues to charge the condenser *C*; as soon as the voltage held by *C* becomes sufficiently high so that enough secondary current flows to balance the bridge the detector tube ceases to conduct. The reading of the ammeter in the secondary circuit is then a measure of the primary current.

If the line current should increase, the detector tube will charge C up to a still higher voltage, increasing the secondary current correspondingly until a new balance point is attained.

If, however, the line current should decrease instead, the detector would increase the charge of C in the same way; but no balance point would be reached because the secondary current necessary to balance the bridge is less than that which is flowing. To take care of this condition the following arrangement is used. First, a high resistance is connected across C causing it to discharge continuously at a moderate rate. Thus, if the line current does not fall too suddenly, the condenser discharges until the secondary current is reduced to the proper value.

The addition of the condenser leak resistance introduces a new feature in the operation of the circuit. If it be assumed that the line current now remains constant it will be apparent that, due to the steady discharge of the condenser, the secondary current will tend still further to be decreased; and that it will fall below the value necessary to balance the bridge. As soon as the bridge commences to unbalance, due to the secondary current being too low, the detector will charge the condenser C some more and this will balance the bridge again. As the charge leaks off again through the resistance the bridge will become unbalanced again and will automatically be corrected again in the same way. This action is carried on continuously all the time so that the bridge is kept balanced by a dynamic or "teetering" principle similar to the way in which a Tirrill regulator operates. This fluctuation takes place at a relatively rapid rate, faster than the ammeter needle can follow, and the instrument furnishes a steady reading in just the same way that the Tirrill regulator keeps a steady voltage on a generator.

Now if the line current should suddenly decrease, so that the bridge rapidly passes through the balance point and becomes unbalanced due to too much secondary current, the detector, will, as before, continue to increase the charge of the condenser C. The voltage held by C will rise and the secondary current will be still further increased instead of being decreased. A Thyratron tube is therefore connected in parallel with C, as shown in the diagram. When this tube

conducts current between anode and cathode the condenser C is instantly and completely discharged.

It will be recalled that a Thyratron tube is a hot cathode mercury vapor tube in which the control action of the grid is such that a negative grid can prevent the flow of current; but when current is permitted to become established by raising the grid to a positive potential, the grid ceases to have any further influence upon the anode current, which is determined entirely by the circuit voltage and impedance. The use of Thyratron tubes in automatic circuits of this type is a somewhat recent development and involves many features of great interest with which engineers have not yet had the opportunity to become familiar. If space permitted it would be desirable to discuss these more extensively. Instead of doing this, however, reference is invited, for a further description of the characteristics and application of Thyratron tubes, to the works of Dr. A. W. Hull, on this subject.

In Fig. 7 the grid of the Thyratron tube is connected in series with a bias battery, to the anode. The battery maintains the grid at a negative potential relative to the anode. As long as the anode voltage is less than that of the battery the resultant voltage between grid and cathode will be negative, and the tube will not pass current. But when the anode voltage becomes greater than the battery voltage the grid will go positive and the tube will allow current to flow. The value of the grid bias voltage is so adjusted that so long as the voltage between anode and cathode—that is the voltage held by the condenser C—is less than the value attained by the condenser when the secondary current reaches the maximum scale reading of the ammeter, the Thyratron tube is entirely non-conducting and has no effect upon the action of the circuit. But, when the line current is suddenly reduced, and the secondary current, already greater than that required to balance the primary ampere-turns, is still further increased by the action of the bridge circuit and detector tube, the condenser voltage increases until it reaches the "off scale" value and the Thyratron tube discharges the condenser. Both the condenser voltage and the secondary current are

now instantly reduced to zero. The bridge is again unbalanced, this time because the secondary current is too low to balance the primary excitation of the bushing transformer. Again the condenser C is charged and the secondary current increased. This time the balance point is encountered as the current rises, the bridge balances and the condenser ceases to be charged. The charge leaks off through the resistance and the dynamic balance condition continues to be maintained.

Thus, when there is a sudden drop in line current the condenser voltage rises, uncontrolled, to a maximum value, is instantly reduced to zero, and rises to the balance point. Thus the function of the Thyratron tube is exactly the same as that of the over-current relay in Fig. 5. But, in the tube scheme system shown in Fig. 7 the ammeter pointer does not fly off scale and return to zero. The action takes place so rapidly that the instrument movement cannot follow it. The pointer moves directly to the lower scale reading corresponding to the reduced value of line current.

Thus it will be seen that in the circuit shown in Fig. 7 the line current is continuously indicated under all conditions, regardless of the manner in which it may vary.

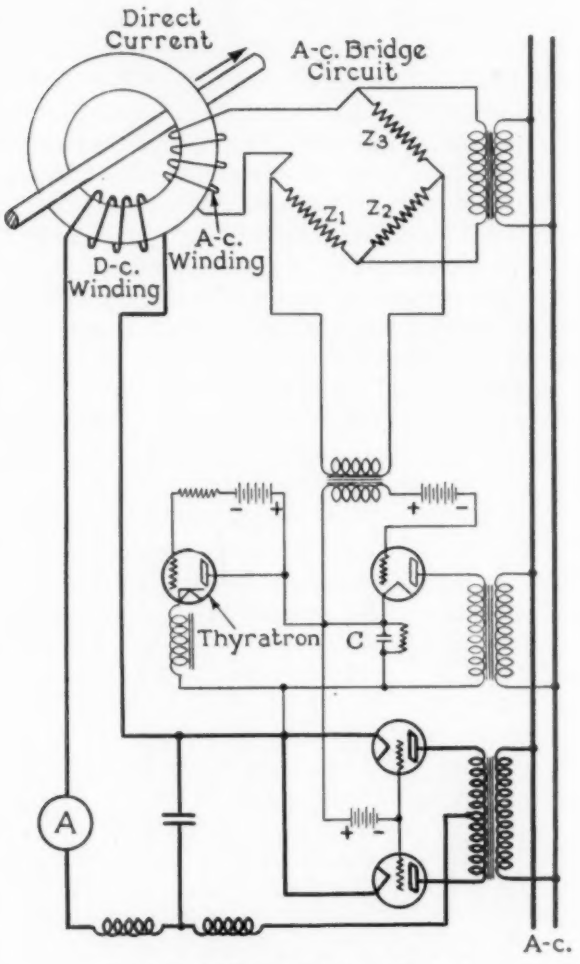
The circuit shown in Fig. 8 is exactly the same as in Fig. 7 except that the secondary current is furnished by two vacuum tubes, connected for full wave rectification, operated from an A.C. anode voltage. This arrangement can therefore be entirely operated from a 110 volt A.C. supply thus dispensing with the 250 volt D.C. source required in Fig. 7.

The arrangement shown in Fig. 9 is similar in its operation to the scheme shown in Figs. 7 and 8. The secondary current is supplied by Thyratron tubes instead of Pliotron tubes. Thus, the secondary current may be of the order of amperes instead of milliamperes. This makes possible the use of fewer turns of larger conductor for the secondary winding of the bushing transformer core, making the latter a more rugged piece of equipment. Since the secondary current must be free from ripple a filter circuit is inserted between the Thyratron tube and the secondary winding.

The circuit shown in Fig. 9 is identical with Fig. 8 with the addition of the two Thyratron tubes and their control circuit. The principle of operation is exactly as already described.

It will be recalled that when a Thyratron tube is operated from an A.C. source the average value of the anode current may be controlled by varying the phase relation between the

FIG. 8.



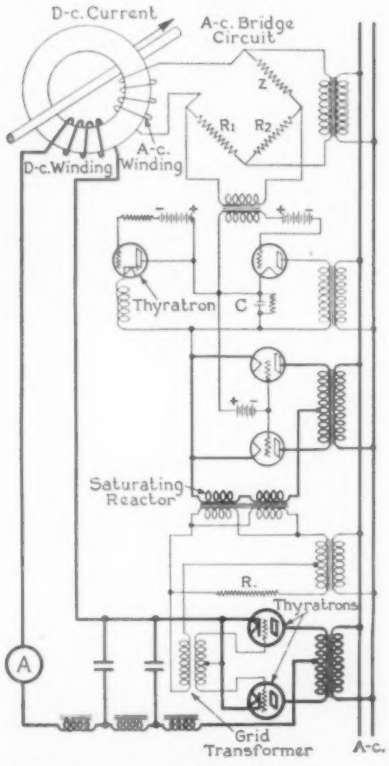
Completely A.C. operated electron tube circuit.

grid and anode voltages. There are a number of different phase shifting circuits by means of which vector displacement of the grid voltage may be obtained by suitable impedance

networks in which one of the impedance elements is capable of being varied, either in resistance or reactance, within the required limits. A further description of these methods may be found in the publications of Dr. Hull referred to above.

In Fig. 9 there is used a network consisting of a fixed resistance and a reactance of which the impedance may be

FIG. 9.



Secondary current supplied by Thyratron tubes.

varied by means of a D.C. saturating current. When the reactance is unsaturated its impedance is high and the grid voltage lags behind the anode voltage. The anode current is then a minimum. When current flows through the saturating winding of the reactor the grid voltage is advanced and the anode current is increased. The saturating winding of the

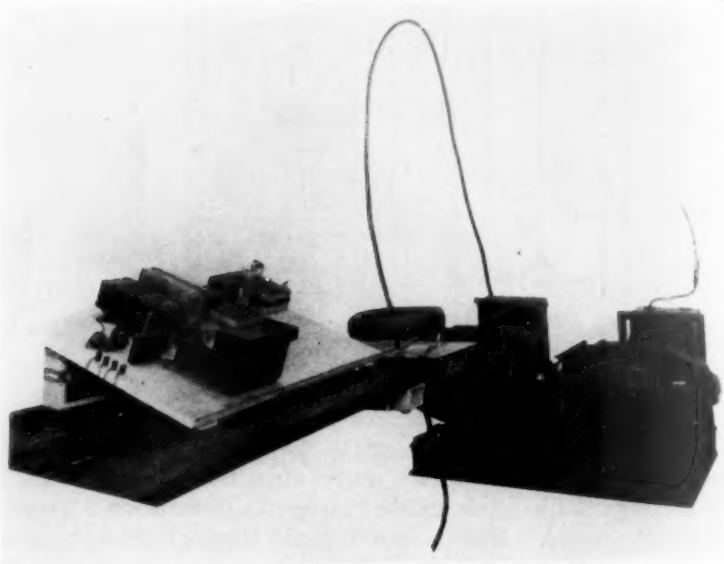
reactor, instead of the secondary winding of the bushing transformer, is connected in series with the anodes of the Pliotron tubes, and the secondary, now of fewer turns of thicker conductor, is supplied from the Thyratron tubes.

NATURE OF TESTS.

A very brief investigation of these circuits in the laboratory sufficed to show that they would operate in the desired manner. No special equipment was built. A few standard electron tube circuit parts were gathered together and a suitable core having a diameter of about 12 inches, was made up from strip material wound up circumferentially. As a convenient means of furnishing a direct current of suitable magnitude a D.C. welding set was obtained. This enabled a current up to around 200 amperes readily to be provided in a single conductor.

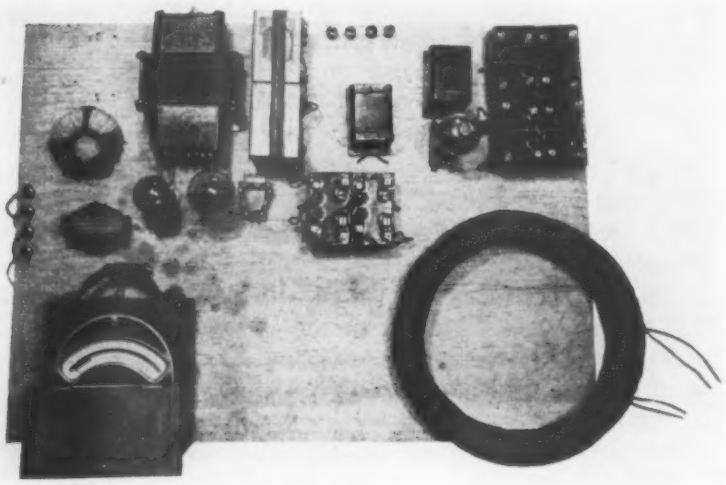
Figure 10 shows the set-up for this investigation. The core and primary conductor can clearly be seen in the photo-

FIG. 10.



Test set-up.

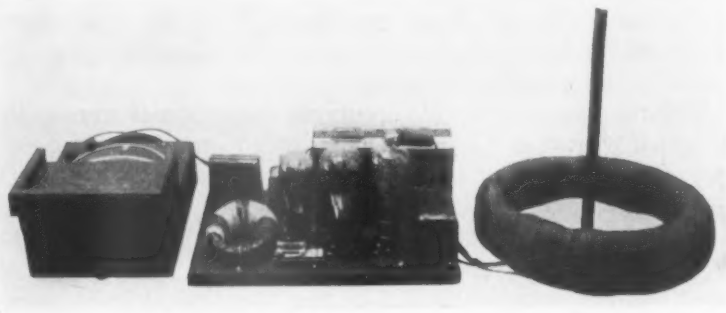
FIG. 11.



Test set-up.

graph. The tube circuit which was used in this case is that of Fig. 7. A closer view of the circuit, core, and measuring instrument is shown in Fig. 11. After sufficient work had been done with this circuit so that the conditions for successful operation became better understood a further and more compact set-up was made. This is shown in Fig. 12. From

FIG. 12.



Test set-up.

this photograph a very good idea of the amount of material required, can be obtained. It seems reasonable to conclude that no very heavy cost may be expected in a commercial equipment based upon these principles.

Circuits according to Figs. 8 and 9 were also set up and operated.

RESULTS OF TESTS.

It will readily be appreciated that the major objective in making this investigation was to see if the schemes described would work. In view of the fact that the use and exploitation of this scheme, and the liquidation of the expenses of development, still lie in the future, it will no doubt be understood that a more prolonged study of the sources of error and the production of an equipment meeting the proper standards of accuracy, suitable for commercial installation would not have been justified at the date this work was carried out.

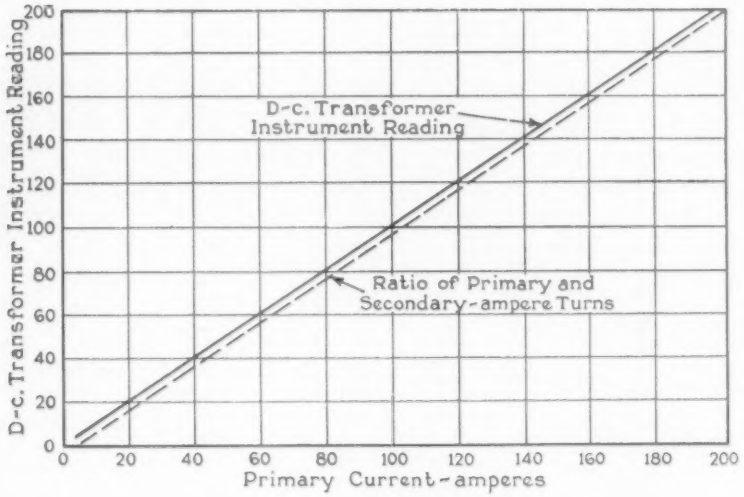
However, the principles on which the circuits are based, and the very promising performance of the rough set-up in laboratory furnish very good grounds for the belief that, when circumstances warrant this further work, no very serious difficulties will be encountered.

The current furnished by the welding set was passed through the permalloy core and also through a standard instrument shunt. Thus the instrument energized by the current transformer could be directly compared with the standard instrument. The line current was varied up and down by means of the field rheostat of the generator; also by short-circuiting the generator at its terminals the current through the bushing transformer could be caused very rapidly to decrease. At all times the readings of the two instruments, as far as could be ascertained by visual observation, seemed to be exactly the same.

The response of the D.C. current transformer versus line current is shown in Fig. 13. The dotted line shows the ratio between the primary and secondary currents. Due to the dynamic balancing principle and to the fact that unbalancing of the bridge must actually occur in order to maintain the continuous hunting or "teetering" action, the secondary current is always slightly below the theoretical value corresponding to the turn ratio. This may be somewhat of an

analogy to the relations between primary, secondary and magnetizing components in an A.C. current transformer. The effect of this condition is that the curve showing the relation between primary and secondary currents intercepts the primary current axis at a value of about 3 amperes as shown in the curve. By off-setting the zero of the instrument in accordance with this intercept the reading of the instrument energized by the bushing transformer was made to indicate primary amperes. Correct readings were furnished

FIG. 13.



Operation of D.C. bushing transformer.

from 3 to 200 amperes. The fact that the arrangement did not indicate below three amperes is possibly not a very serious restriction. Indicating instruments in general are not expected to furnish an accurate reading at such a low portion of their scale.

The accuracy of the scheme is almost entirely independent of the characteristics of the tubes employed, because of the balance or comparison principle which is used. A new set of tubes may be substituted at any time without requiring fresh adjustment and without affecting the instrument reading.

DESIGN.

Several factors enter into the design of the core of the D.C. current transformer. First the D.C. magneto-motive force required to saturate the core must be kept at a low value. This should be one ampere-turn or less if the device is to measure currents up to 200 amperes. The diameter of the core should be a foot or more so as to allow it to fit over a high voltage bushing. Thus the length of the magnetic circuit will be over three feet; and this must be appreciably saturated by one ampere-turn. A special alloy such as permalloy or nicaloi is therefore indicated. Permalloy saturates with a magneto-motive force of 0.2 A.T. per centimeter. It is apparent therefore that the core must be constructed so that only a small portion of the total length saturates, the remainder of the core operating at a low value of flux density. Thus the total reluctance of the magnetic circuit will be substantially equal to that of the saturated section. A constricted portion of approximately 4 centimeters length is used so that one ampere-turn will produce appreciable saturation in this restricted section. The cross-section of the main core is 3.8 square centimeters. The area of the constriction is 0.09 square centimeters. Thus the cross section of the main core is about 40 times that of the restricted section. This makes it reasonable to assume that the total reluctance of the core is that of the constriction.

APPLICATIONS.

The outstanding application of this scheme is, of course, the measurement of direct currents at high voltages for which purpose the circuits were devised. An arrangement substantially as described appears to be suitable for operating indicating instruments. For protective relays higher speeds of response may be obtained by operating the circuit from an A.C. source of a frequency greater than 60 cycles.

It is possible that a reversed arrangement having a multi-turn primary and a secondary of fewer turns might be of value, from the point of view of insulation and safety, for the indication of line voltage in high voltage D.C. systems.

Possible applications in other fields will no doubt suggest themselves to engineers having control and measurement

problems to consider. The lines along which this scheme may possibly be of assistance will, perhaps, be more apparent if we consider the basic function which this device performs.

It matches ampere-turns.

There are at least three reasons why we may wish to do this. First as in the D.C. current transformer, we may wish to maintain a quantitative relation between direct currents in two different circuits which must be isolated one from the other and perhaps insulated for high voltage. Second, we may have a current of a certain order of magnitude which may, perhaps be inconveniently large or too small for measurement, control or whatever function we may have to carry out. This scheme enables us to obtain, by turn ratio, either a multiple or sub-multiple of the given current of an order of magnitude conformable to the purpose involved.

Again a problem which is not uncommon in electrical engineering is the condition where we have a current, in the magnitude of which we are specially interested, which is associated with a circuit of low order of power such that, the impedance of instruments, relays or conducting circuits, especially where distance is involved, may cause errors which are inadmissible. A very good example of such an application is in connection with telemetering systems. The principles described in this paper provide a means of carrying out, without any moving elements or contacts, the well-known current-balance system of telemetering in which a current, independent of the resistance of the connecting line, is maintained in exact ratio to that of the current which is metered.

CONCLUSION.

The work described in this paper was carried out in the Electron Tube Application Laboratories in Schenectady, of the General Electric Company as part of the regular program of applying electron tube principles to electrical engineering problems.

It is a pleasure gratefully to acknowledge the assistance of Mr. E. J. Poitras who carried out all of the laboratory work and calculated the design data, and to whose skill in setting up these circuits the fact that successful operation was readily achieved, is largely due.

A Dictionary of Electrical Engineering Terms.—There is a good possibility that such a dictionary will soon become a reality. One hundred and twenty scientists forming a committee under the chairmanship of DR. A. E. KENNELLY of Harvard University have worked for three years to evolve this standard dictionary of terms. The results of their labor will be submitted in the form of a report to the American Standards Association for adoption as an American Standard. The report is a document of 208 pages listing over 3,400 definitions ranging from the purely fundamental, on which the science of electricity is based, to definitions for practical applications, such as those for control equipment, generation, transmission and distribution, welding, illumination, wire and radio communication, electrobiology and electro-therapeutics.

C.

Food and Drug Seizures.—The doings of the Federal Food and Drug Administration do not seem to be accorded widespread publicity. As a result, few people get the opportunity to appreciate just how well the Administration safeguards our health and well-being. One cannot help being disquieted by the announcement that in one month 645 one-pound cans of adulterated canned crabmeat were seized as being contaminated as a result of packing under unsanitary conditions. However, this was surpassed by the seizure of over 4,000,000 cans of decomposed salmon. In the field of drugs, a seizure of "cactus butter" made interesting news. The product was labeled as being "compounded from natural vegetable food elements . . . a combination of selected nuts, combined with the latex of cactus of the two families . . . stimulates, cleanses, revitalizes and restores normal functions of the glandular system . . . feeds the nerves.

In September, eleven cases of legal action ended with the payment of fines for violation of the Food and Drug laws. These included candy misbranded as milk chocolate, Tuttle's Family Elixir, a cureall; Numoss, good for all respiratory diseases; Kreitzer's Salve for skin troubles; jellies containing undeclared pectin, decomposed tomato catsup, misbranded wheat shorts and incorrect labeling of drugs coming under the Caustic Poison Act.

C.

THE FRANKLIN INSTITUTE ECLIPSE EXPEDITION

BY

JAMES STOKLEY,

Associate Director, The Franklin Institute Museum.

One of the features of the astronomical section of the new Franklin Institute Museum will be a long focus solar telescope which will show a nine inch image of the Sun, with any spots that may be visible, on a screen in the lobby of the Fels Planetarium. This will consist of a coelostat with two mirrors, to reflect the Sun's light down a vertical shaft from the roof, and a lens of 85 feet focal length, which will form the solar image on the ground floor. The optical and mechanical equipment for this telescope were ordered from J. W. Fecker, of Pittsburgh, and were promised for delivery early in the summer of 1932.

After the order had been placed, it became apparent that the museum's new building on the Parkway would not be ready in 1932, and so the coelostat and long focus lens would be available for use at the eclipse of August 31st. When the matter was broached to Mr. Gustavus Wynne Cook, of Wynnewood, Pa., a member of the Institute and an enthusiastic amateur astronomer, he kindly offered to make the funds available for a Franklin Institute Eclipse Expedition.

Following some preliminary correspondence with various local authorities in the path of the total eclipse in Maine and New Hampshire, it appeared that the vicinity of Conway, N. H., would be a favorable location. Studies of past weather records indicated that this region had as good chances for clear weather as any point on the path, and that it was somewhat more favorable than a position nearer the coast. It was within a few miles of the center of the eclipse track, and good railroad connections would facilitate the shipment of apparatus. Furthermore, no other expeditions had chosen this point, and, because of the possibility of scattered clouds, a special effort was made to distribute the various expeditions as widely as possible.

In February, therefore, the writer visited Conway, and was shown a number of possible locations by Mr. Arthur W. Evans, secretary of the Chamber of Commerce. A large field, close to the center of the town, and adjoining the grounds of the A. Crosby Kennett High School, was found to have many advantages, particularly if the school building could be used for headquarters. Mr. Frank H. Kennett, owner of the field, and president of the School Board, and Mr. Ellis McKean, headmaster of the school, very kindly arranged to have the building and grounds made available.

The use and adjustment of the coelostat has been fully described elsewhere,[1] so it will suffice here to say that it consists of a plane mirror which rotates once in two days from east to west around an axis in its plane and parallel to the Earth's axis. The image of a star reflected from such a mirror remains in a fixed position with respect to the Earth. By setting the mirror at an angle to the polar axis, it is possible to throw the reflected beam in any direction, but then there is a rotation of the image. When the polar axis coincides with the plane of the mirror, the image is reflected towards a point in declination of the same value but opposite sign to that of the object under observation. If the telescope, which the coelostat feeds, is horizontal, its azimuth must be adjusted according to the declination. For morning observations, the telescope is directed towards the setting point of the object, and for afternoon observations, it is directed towards the rising point.

As the eclipse occurred in the afternoon, it was necessary that the camera be directed to the sunrise point for the Sun's position at eclipse time, which was 11° 52′ north of east. Obviously, a camera 85 feet long could not easily be made adjustable, but must be built in place, which required that its position be carefully laid out. Accordingly, Prof. Wm. H. Barton, head of the department of civil engineering and director of the Hyatt Observatory of Pennsylvania Military College, and the writer visited Conway in June to locate the instruments, using a transit very kindly loaned by Mr. J. Henry Warren, of the Warren-Knight Co., Philadelphia.

Following our visit, the large camera was constructed by

[1] H. H. Turner, *The Observatory*, **56**, pp. 408–423.

Mr. Waldo E. Bickford, a local builder. It consisted of a light-tight shack, 10′ × 12′, provided with a lightproof entrance. From the eastern side of the shack, in the proper azimuth, extended two square tubes, one 85 feet long, the other 40 feet long. The latter was for a lens of the latter focal length, which was loaned, together with another coelostat to feed it, by Mr. Cook. The larger tube was four feet square at the shack end, and two feet square at the objective end. The shorter tube was two feet square for its entire length. At the eastern ends of the tubes were heavy wooden piers to support the instruments, with no connection between the piers

(Photo by G. W. Cook.)

Polar axis and drive for the 60 inch, 30 inch and 23 inch cameras of The Franklin Institute eclipse expedition. The drive was from the shaft of the coelostat on the table to the left, which was also used for motion picture equipment. Several other instruments were mounted on the polar axis at eclipse time.

and tubes. Inside the shack, in line with the tubes, were two other piers, to support the plateholders. Plates 20″ × 24″ were used with the 85 foot camera, and plates 10″ × 12″ with the 40 foot. The latter was also used to photograph the partial phases of the eclipse. For this, there was placed over the tube opening a sliding shutter, which could be dropped rapidly, a narrow slit giving the plate a brief exposure. As the shutter dropped, a contact was made to the pen of a chronograph, thus giving an accurate time record of the eclipse. It could also be raised completely, exposing the entire opening, for the longer exposures during totality.

The shutter was operated by a catch, released by a cord terminating near the objective, and was reset by a person in the dark room.

Both coelostats mentioned are provided with electric drives. In addition, the Institute has a coelostat used by the Naval Observatory at the transit of Venus in 1882 and loaned for exhibition purposes by the Navy Department. This instrument is driven by a falling weight. Because of its immunity to difficulties from possible failure of the power supply at the critical moment, this was used with the 85 foot lens. The Franklin Institute coelostat was employed with motion picture equipment. On both of these coelostats, stainless steel mirrors, made by Mr. Fecker for use with the Institute's instrument, were used.

While the long focus lenses would give large scale pictures of the inner and middle corona, their small relative aperture, F. 170 in the case of the 85 foot lens, would prevent their photographing any considerable extension of the coronal streamers. To complete the record, it was decided to use several smaller lenses, of large relative aperture, in cameras mounted on a polar axis. Three lenses were obtained for this purpose, as follows: an astrophotographic lens of 4 inches aperture and 60 inches focus, loaned by Mr. Fecker; a Carl Zeiss Apo-Tessar of 30 inches focus and F. 10 relative aperture, loaned by Carl Zeiss, Inc.; and a Bausch and Lomb Tessar of 23 inches focus and F. 6.3 relative aperture, loaned by the Bausch and Lomb Optical Co.

The cameras, the polar axis and the drive were constructed in the shops of The Franklin Institute, and shipped to Conway. The axis consisted of a box one foot square and five feet long, through the center of which passed a one inch steel rod. The rod was supported at top and bottom on standard ball-bearing pillowblocks, which were placed on wooden piers erected at the location, so that the axis of the box was parallel to that of the Earth. For the drive, another rod was clamped to the lower end of the axis, to project on the western side. As this rod fell, the axis was turned from east to west. Its fall was regulated to the proper speed by a cable, the other end of which was wrapped around a drum on the drive shaft of the motor driven coelostat. By changing the point of the

cable's attachment to the rod, a delicate adjustment of the rate could be obtained, and the axis, together with the cameras mounted on it, made to follow the Sun precisely.

Two motion picture cameras were set up to photograph the entire eclipse. Together with other motion picture equipment, these were furnished by Paramount Sound News, and operated by Mr. Phil Coolidge, of their office in Boston, together with several assistants. One of these cameras was provided with a 25 inch focus apochromatic lens of F. 9 relative aperture, loaned by the Bausch and Lomb Optical Company, and the other with a 24 inch, F. 6.3 Carl Zeiss Tessar, loaned by Carl Zeiss, Inc. The motor driven coelostat mentioned above was used to feed one of the cinema cameras, the other being used with a small spring driven instrument. This was loaned by Mr. Cook, who uses it on his spectrohelioscope. With other motion picture cameras, mounted on the usual tripods, the Paramount representatives photographed the eclipse with lenses of shorter focus, and also made a complete record of the activities of the expedition.

After the plans of the expedition were announced, Dr. Marion Eppley, of Newport, R. I., very kindly offered to provide and operate pyrheliometric equipment which would measure the radiation of the eclipsed Sun. This offer was readily accepted. The pyrheliometer cells were erected on the field on wooden towers ten feet high, and connected with Leeds and Northrup recorders in the school building. One group of cells measured total radiation, while another was shielded from the direct rays of the sun. In order to measure the coronal radiation an arrangement suggested by Dr. Seth B. Nicholson, of the Mt. Wilson Observatory was used. This consisted of two tubes, containing no optical parts, but provided with several diaphragms through their length so as to cover a limited area of the sky, about three degrees in diameter. Thermocouples at the other end detected the heat radiation from these regions. The tubes were mounted on the polar axis, and connected with measuring instruments in a nearby tent. One tube was pointed directly towards the Sun, the other to an area of the sky immediately adjacent to it. Thus, the former, as used at eclipse time, according to plan, would measure sky radiation plus that from the corona,

while the latter would measure sky radiation alone. The difference, therefore, would presumably be coronal radiation. The two were connected to the meters so that one balanced the other, and readings of the difference obtained directly.

Several other kinds of observations were planned by various members of the expedition. Mr. Charles Bittinger, prominent artist of Washington, D. C., and Duxbury, Mass., who has painted a number of scientific subjects, was prepared to paint the eclipse in oil. He was assisted by Dr. Herbert E. Ives, of the Bell Telephone Laboratories. Dr. Ives also

(Photo by G. W. Cook.)

The long focus camera of The Franklin Institute eclipse expedition at Conway, N. H. The lens, coelostat and tube of the 85 foot camera are at the right, and of the 40 foot camera to the left. Both formed images in the shack at the far end.

brought a Weston photronic cell and milliammeter, which was used to measure sky illumination, the cell being placed on the end of an equatorially mounted telescope, and continually directed towards the Sun. A standard Weston illuminometer, operating similarly, was loaned by Dr. C. D. Fawcett, of the Moore School of Electrical Engineering of the University of Pennsylvania. Readings of the meters during the eclipse were taken by Dr. S. K. Brecht, of the Overbrook High School, Philadelphia.

Two groups attempted to photograph the shadow bands. Mr. H. F. Balmer, of Toronto, was prepared to photograph them directly. Mr. Russell W. Porter, of the California Institute of Technology, assisted by a group of amateurs from

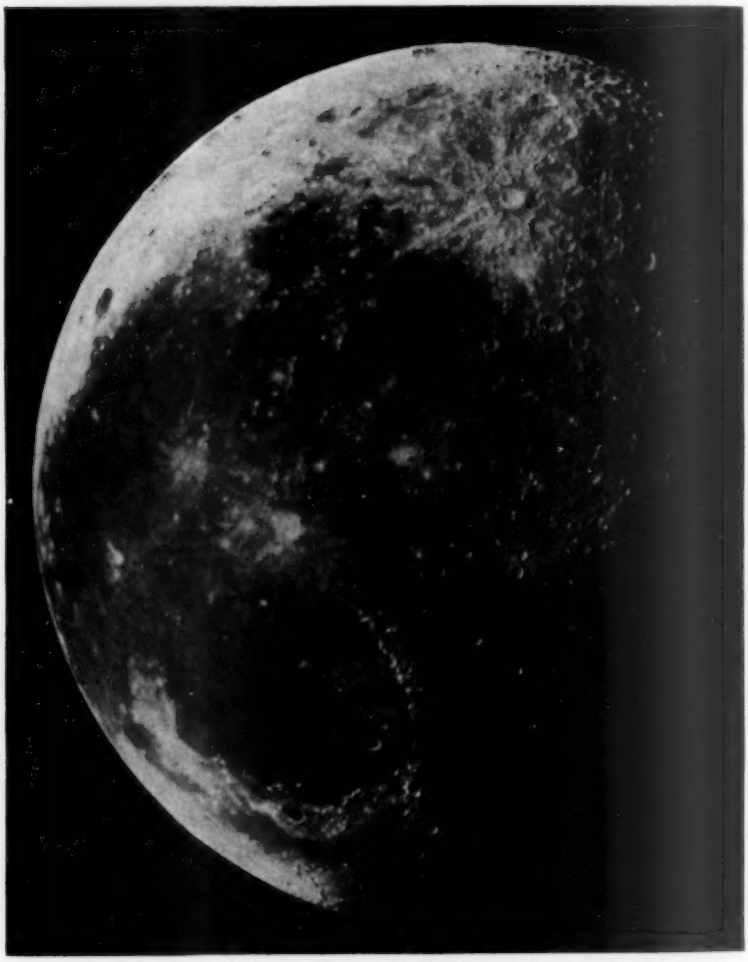
Springfield, Vermont, made a similar attempt with a camera equipped with an F. 2.7 lens. He also tried a method originally used by Dr. H. T. Stetson in 1925, in which a camera without a lens is placed a little outside the focus of a large concave mirror, forming essentially a Herschelian telescope. This gives an out of focus image of the crescent Sun, on which the shadow bands should appear.

M. J. W. Fecker tried color photographs of the corona using a 5 inch equatorial telescope on a portable mounting, equipped with an apochromatic lens, a Warren telechron motor drive, and a Graflex camera attached to the ocular end. Mr. L. V. D. Bucher was also equipped for color photography, using a six foot focus lens loaned by the Hyatt Observatory of Pennsylvania Military College. Using apparatus prepared by Prof. Wm. H. Barton, Mr. George Frick tried to record the times of the contacts, by filming with a 16 mm. motion picture camera a screen holding two stop watches and on which was projected an image of the Sun by a telescope lens. Mr. Charles E. Bonine, associate director of The Franklin Institute Museum, used a Leica camera equipped with a special long focus lens, which was intended for photographs of the partial phases and of the corona. Mr. Arthur Louis Sands, pen and ink artist of Boston, was prepared to sketch the corona.

On Sunday, August 28, final rehearsals of the eclipse program began, with every person in position as for the eclipse. The time was counted by Prof. A. Clyde Schock, of the Central High School. In order that the counts could be heard plainly in all parts of the field, and in the dark room of the large camera, a public address system, loaned by Mr. Evans, was used to amplify the speaker's voice. Making the exposures at the objective end of the 85 foot camera was Dr. Curvin H. Gingrich, editor of *Popular Astronomy*. In the dark room, to change the plates, were the writer and Mr. Leonard Ormerod. Mr. John S. Allen, of Colgate University, made the exposures at the 40 foot lens, both for the partial phases and for totality. Mr. I. M. Levitt changed the plates, and was joined in this during totality by Dr. George Rosengarten, of the Philadelphia College of Pharmacy and Science.

Two persons operated each of the cameras on the polar

axis, one making the exposures, the other changing the plates. The exposures were made by Mr. Howard Carl, Mr. Aldo Aldeghi, and Mr. David Auspitz; the plates were changed by



The Moon, photographed with the 85 foot focus coelostat camera of The Franklin Institute eclipse expedition at Conway, N. H., 1932 August 21.

Mr. Harry B. Rumrill, president of the Rittenhouse Astronomical Society, Prof. Wm. H. Barton, and Mr. George Rosengarten, Jr.

The lenses were focussed by test exposures on stars and also, in the case of the 85 foot lens, on the Moon some days previous to the eclipse. For the eclipse exposures during totality, a special plate, recommended by Dr. C. E. K. Mees, director of the Research Laboratory of the Eastman Kodak Co., was used in the 85 foot and 40 foot cameras. They were double coated, using the regular Eastman 33 emulsion over which was the Eastman 40. The Eastman lantern slide emulsion, on 10″ × 12″ plates, was used for the 40 foot partial phase exposures. In the smaller cameras Eastman 40 and Wratten and Wainwright panchromatic plates were used. All the plates were backed, and they were developed in one of the laboratories of the school, which was fitted as a dark room and served the purpose admirably.

Cloudy weather on a number of afternoons previous to the eclipse offered some discouragement. Early in the morning of the 31st, it was cloudy, but the sky cleared, until about noon, when the Sun shone brilliantly. By two o'clock, however, clouds began to gather in the west, over the mountains. First contact came at Conway at 2:19:28.9 p.m., eastern standard time, and shortly afterwards the advancing limb of the Moon could be seen over the Sun, with the aid of a 4 inch telescope set up for visual observations. An exposure made with the 40 foot camera at 2:20:00 shows this clearly. The clouds continued to increase. Second contact was due at 3:28:17.5, and five minutes before that, the narrow crescent of the Sun could still be seen, through the clouds. By the time of totality the clouds covered the Sun almost completely, though a few persons who were observing the eclipse visually reported a glimpse of a red glow, which was probably one of the brighter prominences.

Despite the clouds, however, the entire observing program was carried through, and during the 98.8 seconds of totality 27 plates were exposed, including 6 with the 85 foot camera, which had exposures varying from 2 to 40 seconds. It was hoped that, by some miracle, the photographs might cut through the clouds, but this was not the case. When the plates were developed, it was found that a few of those made with the smaller cameras showed a faint ring of light, consisting of the inner corona, but they are not sufficiently good

Partial phases of the eclipse of 1932 August 31, photographed with the 40 foot focus coelostat camera by The Franklin Institute expedition at Conway. The left hand exposure was made at 2:20 P.M., E. S. T., and the limb of the Moon can be seen on the right hand edge of the solar disc. The exposure to the right was made at 3:10 P.M., and the clouds can be plainly seen.

to enable a satisfactory print to be made. After the eclipse the clouds continued to increase, and the Sun was not seen again that afternoon.

The pyrheliometer records were found to show a decrease in radiation, to approximately that of night time, during totality, but no significant results were obtained with the thermocouples mounted on the polar axis.

The regrets of the members of the party at their failure to obtain any results of value was lessened when it was learned that the disappointment had been shared by only about half of the twenty large expeditions along the path of totality. Though none of the parties seem to have had an absolutely clear sky, a number of them obtained excellent photographs, some of which showed coronal streamers extending to about three diameters from the Sun. The best positions seem to have been along the coast and the poorest inland, in direct contradiction to advance prognostications. Thus, the scientific record of the eclipse is complete, and it makes little difference which parties made the successful plates. Events showed conclusively the wisdom of scattering the expeditions so freely, as otherwise all might have had the same ill luck.

The writer wishes to take this opportunity, on behalf of The Franklin Institute, of expressing its gratitude to the numerous persons and organizations who so generously coöperated. Especially deserving of thanks is Mr. Gustavus Wynne Cook, not only for the equipment which he loaned from his private observatory, but particularly for his financial support which enabled the expedition to be sent. Thanks should also be given to the Bell Telephone Laboratories, for the loan of a short wave radio set and amplifier, to receive time signals; to Mr. William C. Bond, of Boston, for the loan of a chronometer making seconds contacts, to operate the chronograph; to the Western Union Telegraph Co., for the loan of a relay; and, for the loan of equipment mentioned before, to Dr. Marion Eppley, Mr. J. Henry Warren, Mr. J. W. Fecker, Dr. C. D. Fawcett, the Bausch and Lomb Optical Co., Carl Zeiss, Inc., and Paramount Sound News. The Conway Chamber of Commerce, Mr. Frank H. Kennett, and other local authorities, should be thanked for their complete coöperation and assistance, in making our visit one to be long

remembered with pleasure. The New Hampshire National Guard is also entitled to our gratitude. Two companies were encamped on the field adjoining the eclipse grounds, and these men, with characteristic efficiency, aided the local police in guarding the grounds, and keeping out unauthorized visitors, as the urgency of the operations made it impossible to have the field open to the public. The Columbia Broadcasting System made its headquarters at Conway, and the progress of the eclipse and the activities of the observers were described over an international radio network by Mr. Ted Husing. To him, and the Columbia engineers, thanks should go for their assistance. Finally, the writer wishes to thank the various members of the party for their complete and cordial coöperation, as a result of which the entire expedition was carried out without friction of any kind.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

CORROSION OF KNITTING NEEDLES.

Considerable trouble has been reported in the knitting of silk stockings, owing to the corrosion and pitting of individual needles in the transfer and knitting bars. The transfer bar, which consists of a series of steel needles arranged parallel to each other and held firmly at one end between two strips of metal (usually steel, brass, or both) is used for transferring the partially completed stocking from one set of needles to another. A line of shallow pits on the needles, which are generally produced after the needles have been in service for some time, leads to a roughening of the needle, whereby the thread of the weave passing around the needle is caught and torn. Consequently, stockings of inferior grade are produced which necessitates the removal of the transfer bar and the installation of a new one.

The results of some laboratory tests carried out at the bureau indicate that this difficulty is due in large measure to "contact corrosion" between the needle and the thread which is kept wet with an oil-emulsion. The emulsion examined was sufficiently corrosive to produce a slight attack on the steel at those points where the thread was in contact with the needle for several hours. Corrosive attack similar to that obtained in service could thus be reproduced in the laboratory.

The remedy for this difficulty evidently lies in the modification of the oil emulsion, whereby no corrosive action on the steel occurs, or in the use of a more resistant metal.

DETERMINATION OF LEVULOSE IN CRUDE PRODUCTS.

Research Paper No. 426 in the April, 1932, number of the *Bureau of Standards Journal of Research*, dealt with the physical properties of levulose and means for its estimation. As a sequel to this, Research Paper No. 495, which will appear

* Communicated by the Director.

in the November number of the *Journal*, describes in detail the methods of analysis of crude substances which contain levulose. These methods have been devised mainly for the purpose of controlling the process of levulose manufacture from the juices of the Jerusalem artichoke, but are equally valid for the analysis of other crude materials. Specifications are supplied for the hydrolysis of polysaccharides, clarification, analysis for total reducing sugar, and selective analysis for levulose. The methods are applied to honey and various fruits, in most of which levulose is found to be the predominating sugar.

CONCENTRATION OF THE ISOTOPE OF HYDROGEN IN WATER.

Water formed by burning hydrogen from a tank of commercial electrolytic hydrogen was found to have a density greater than ordinary water by about three parts in a million, thus showing that this tank of electrolytic hydrogen had been produced by the electrolysis of water already considerably concentrated in the H^2 isotope. The isotopic composition of commercial tank hydrogen is, therefore, variable, depending upon the age of the electrolyte in the cells from which the hydrogen happened to come. Hydrogen produced by the electrolysis of a large quantity of ordinary water, when burned produced water of a lower density than ordinary water, the decrease in density being about three parts in a million. Hydrogen produced in the laboratory, therefore, by the customary processes consists almost entirely of the H^1 isotope. An experiment is now under way to prepare a considerable amount of this low density water for the purpose of re-electrolyzing it to see whether any further decrease in density takes place.

SENSIBILITY TO COLOR-TEMPERATURE CHANGE AS A FUNCTION OF TEMPERATURE.

It is possible to estimate the temperature of many incandescent substances from the color of the light which they emit. For example, it is common knowledge that the temperature of red-hot iron is lower than that of iron which gives off a more yellowish-red light. Similarly, the temperature of the yellow candle flame is lower than that of the filament

of a modern incandescent lamp which gives off light of a more whitish yellow.

The color of the light emitted from a hot surface, although chiefly determined by the temperature of the surface, also depends somewhat on the character of the surface. A convenient standard of reference, which avoids the uncertainty of the surface character, is the light from a small hole in a uniformly heated inclosure. It has been proved that both the intensity and color of this light are dependent only on the temperature of the inclosure no matter what material lines the inside of the inclosure. When the light from an inclosure gives a color match with the light from a heated surface, the *color temperature* of the heated surface is defined as the temperature of the inclosure. The true temperature of the heated surface may differ considerably from its color temperature. In this way the relation between color and temperature may be made to form the basis of precise measurement. Thus, red-hot iron has a color temperature of about 800° on the absolute (or Kelvin) scale of temperature; a glowing cigar end has a color temperature of about 1,000° K.; a candle flame yields about 1,800° K.; a modern incandescent lamp gives about 2,800° K.; the carbon arc, 4,000° K.; and the sun, about 6,000° K.

An investigation has been made at the bureau to determine how rapidly the color changes as color temperature is varied. It has been found that the color changes with temperature more rapidly at low than at high temperatures. For example, it is easily possible to tell the difference in color between two sources whose color temperatures differ by 100° near 2,000° K., but this same temperature difference at 6,000° K. would ordinarily go unnoticed. A much more convenient indication of color difference is afforded by the reciprocal of the color temperature; it is suggested that reciprocal color temperature might with advantage often be used instead of color temperature.

THERMAL EXPANSION OF MAGNESITE TO 1,800° C.

Among the refractory materials included in an investigation of the linear thermal expansion of special refractories from atmospheric temperature to 1,800° C., are four samples

of magnesite as follows: (1) Austrian, (2) electrically fused, and (3) two from California representing different deposits.

Expansion data were obtained for these materials on specimens 6 inches long and 1 inch in cross-section after heating at two different temperatures; either 1,400° or 1,580° C., and in all cases to 1,800° C. In general the expansions of the four magnesites are similar; although the total may vary somewhat, the rate in all cases is uniform with a tendency to increase as the temperature increases. Heating the specimens to the different temperatures did not greatly affect their expansions except that contraction occurred of the specimens fired to the lower temperatures close to the temperature to which they had been heated before testing.

The maximum total expansion of the Austrian magnesite after heating to 1,800° C. was 2.43 per cent. It was obtained at 1,500° C. The specimen contracted after reaching this temperature even though it had been preheated to 1,800° C. and differs from the others in that respect. The average coefficient of expansion from 20° to 1,500° C. was 16.4×10^{-6}. The petrographic examination shows the raw material to be very heterogeneous. It contains approximately 85 per cent. of an isotropic material having an index of refraction ranging from 1.73 to 1.76.

The electrically fused magnesite showed a maximum total expansion of 2.45 per cent. after heating to 1,800° C. It was obtained at 1,800° C. The average coefficient of expansion from 20° to 1,500° C. was 13.2×10^{-6}. The petrographic examination shows this material to be very pure. It is composed of over 90 per cent. periclase and less than 1 per cent. glass. The two magnesites from California differ in their content of impurities. The one sample was furnished in brick form, and the petrographic examination indicated it to contain between 90 and 95 per cent periclase. The maximum total expansion after heating to 1,800° C. was 2.57 per cent. It was noted at 1.765° C. The average coefficient of expansion from 20° to 1,500° C. was 14.2×10^{-6} and compares with 14.7×10^{-6} obtained on the second sample furnished in bulk form. The maximum expansion, 2.35 per cent., was obtained at 1,630° C., the highest temperature reached after the specimen had been heated to 1,800° C.

REACTION OF WATER ON CALCIUM SILICATES.

Any explanation of the setting of Portland cement must take into consideration reactions in the system lime-silica-water. A portion of this system at 30° C. has therefore been investigated with especial reference to the hydration and hydrolysis of calcium silicates.

The reactions of tricalcium silicate and beta-dicalcium silicate with water involve simultaneously two processes: (1) the formation of metastable and supersaturated solutions of progressively greater lime concentration and decreasing silica content; (2) precipitation of hydrated calcium silicate containing increasing proportions of lime from such solutions. Monocalcium silicate, which is nonhydraulic, gives solutions which do not show this continuous change.

Decomposition of supersaturated silica solutions prepared over a wide range of lime concentrations permitted construction of the stable solubility curve as well as determination of the compositions of precipitates in contact with the solutions at equilibrium. Application of the Freundlich adsorption isotherm showed that initially the solid phase consists of hydrated silica which reaches its maximum solubility of 0.326 gram SiO_2 per liter at a lime concentration of 0.070 gram CaO per liter. Subsequently a rapid rise in lime content of the solid phase occurs to the molar ratio $CaO/SiO_2 = 1 : 1$ and several lines of evidence point here to the formation of a definite hydrated calcium silicate. The existence of hydrated compounds of higher lime content has not been proved or disproved although the solid phase approaches a molar composition of $2CaO : 1SiO_2$ when in contact with saturated lime solutions.

It has been shown that the same equilibria can be approached in the reverse direction by the reaction of diatomaceous silica upon lime solution whereby the lime content of the former is increased at the expense of that in solution until the appropriate relation between composition of solid phase and solution is attained.

DENSITY AND REFRACTIVITY OF SOME SODA-LIME GLASSES.

Reference to this subject was made in Technical News Bulletin No. 179 (March, 1932). The statement in that item

referred to refractivity for yellow light. The work has been extended to include the refractivities of these glasses for the lithium red (6707.8), mercury green (5460.7), and mercury blue (4358.3A) lines. Within the limits of accuracy of the measurements made (0.0004) the refractivities for the various wave-lengths are linear functions of the squares of the frequencies. The relations may be expressed by the empirical equation:

$$N = A + K(0.4540 - V) + K'C,$$

in which N is the refractivity for any wave-length, A is the refractivity of fused quartz for that wave-length, V is the specific volume of the glass under consideration, C is the percentage of lime in that glass, $K = 0.8164 + 2780000D$ and $K' = 0.00128 - 4274D$, D being the square of the frequency for the given wave-length.

It is thought the equation given above can be safely used to determine with fair accuracy the index of refraction of any of the glasses studied for any wave-length between 7681.9 and 4046.6A.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, NOVEMBER 16, 1932.

The regular monthly meeting of The Franklin Institute was called to order at eight-sixteen P.M. by Mr. W. Chattin Wetherill, Vice-President, who was the presiding officer.

At the outset, Mr. Fred W. Johnson, a representative of the United Campaign, was permitted to speak for five minutes in advocacy of the campaign for funds for the needy of Philadelphia which is being conducted by this organization.

At the end of this feature, the Chairman presented the speaker of the evening, Dr. James Shelby Thomas, who spoke delightfully on "What the Machine is Doing to Mankind." Dr. Thomas portrayed statistically the effect of the machine upon labor and mankind and combated the statements of the litterateurs and other writers who have ascribed all present evils to the machine. His talk made a very pleasing impression upon a very interested audience.

At the end of the talk of the evening, the Secretary presented the following items of business.

He announced that the minutes of the October meeting had been printed in full in the November number of the JOURNAL and stated that unless objection were offered, the minutes would be regarded as approved as printed.

He made the following report on membership: five new resident members; four new non-resident members; five deaths (which are reported elsewhere in this number of the JOURNAL).

The Secretary then called to the attention of the membership and friends of the Institute the subject and the character of the Christmas Week Lectures for Young People, which will be held on December twenty-seventh, twenty-eighth and twenty-ninth. He stated that the lecturer will be Mr. E. N. Fales, an aeronautical engineer, and former instructor in aeronautics in the University of Michigan. He assured the audience that the lectures would be excitingly interesting and urged that tickets for the series be presented as Christmas presents to young people who should be interested.

After an expression of appreciation of Dr. Thomas' talk, and of thanks on the part of the Institute for his visit, the meeting adjourned at nine-twenty-nine P.M.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, November 9, 1932.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 9, 1932.

MR. EDWARD L. CLARK *in the Chair.*

The following reports were presented for final action:

No. 2947: Non Winding Clock.

This report recommended the award of the Certificate of Merit to Mr. Arthur F. Poole, of Ithaca, New York, "In consideration of his combination in a battery operated clock, of known mechanisms, that has produced a clock in which the swing of the pendulum is the driving force of the gears controlling the hands, and also determines the frequency of the impulse, that requires battery renewal at long intervals only, and that is an accurate time keeper."

No. 2955: Railway Car Cushion Underframe.

This report recommended the award of the George R. Henderson Medal to Mr. Otho C. Duryea, of New York City, "In consideration of the meritorious railway engineering and the novel feature embodied in the invention of the Duryea Railway Car Cushion Underframe."

No. 2958: Planetarium.

This report recommended the award of the Elliott Cresson Medal to Doctor Walther Bauersfeld, of Jena, Germany, "In consideration of the invention of a mechanical and optical device to produce on the inside of a white hemispherical screen the naked eye stars and planets as seen from any part of the earth at any time and to represent their motions, so speeded that changes taking many centuries can be shown in a few minutes—the whole constituting an apparatus which has proven of exceptional value in explaining astronomy to the layman as well as for the solution of technical problems."

The following report was presented for first reading:

No. 2928: Stream-Line Filter.

GEO. A. HOADLEY,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, November 16, 1932.*)

RESIDENT.

MR. HARRY GLAENZER, Vice President and Chief Engineer, The Baldwin Locomotive Works, Paschall Station P. O., Philadelphia, Pa.

MR. EDWARD P. LANGLEY, Insurance (Retired), The Belgravia, 1811 Chestnut Street, Philadelphia, Pa.

MR. ELMER LATSHAW, Engineer, J. G. Brill Company. For mailing: 1839 North Sixtieth Street, Philadelphia, Pa.

NON-RESIDENT MEMBERSHIP.

MR. CHARLES E. DAVY, Director-Engineering Operations, Chrysler Corporation, Detroit, Michigan.

MR. R. MAX GOEPP, JR., Chemist, Atlas Powder Company. For mailing: 1 Lehigh Street, Tamaqua, Pa.

CHANGES OF ADDRESS.

MR. HAROLD ASHWORTH, 623 West Cliveden Avenue, Philadelphia, Pa.
MR. J. C. DACOSTA, 3D, Birchrun, Haslemere, Surrey, England.
MR. MILTON W. DEISLEY, 134 North Prince Street, Lancaster, Pa.
MR. F. LYNWOOD GARRISON, 1019 Clinton Street, Philadelphia, Pa.
MR. JOHN H. GIBSON, Red Gables, Dogwood Lane, Rye, New York.
MR. PERCY TATE GRIFFITH, 125 Woodbine Avenue, Larchmont, New York.
DR. EDWARD GUDEMAN, 332 South LaSalle Street, Chicago, Illinois.
MR. W. J. JEFFRIES, 923 Ormond Avenue, Drexel Hill, Pa.
MR. CLARENCE N. JOHNSON, 170 Tysen Street, New Brighton, Staten Island, N. Y.
MR. ROLAND W. JOHNSON, 336 Vernon Road, Germantown, Philadelphia, Pa.
MR. EARL L. KOCH, 4938 North Talman Avenue, Chicago, Illinois.
MR. D. F. KRAMER, Supervisor of Signals, Reading R. R. Company, Harrisburg, Pa.
MR. A. LESLIE LAMBERT, 612 Shady Lane, Narberth, Pa.
MAJOR FRANK M. MASTERS, 502 Keystone Building, Harrisburg, Pa.
DR. GEORGE D. ROSENGARTEN, Royal Palm Dock, Miami, Florida.
MR. JAMES L. SCHWANK, Southwest corner Pleasant and Ardmore Avenues, Wyndmoor, Pa.
MR. H. BIRCHARD TAYLOR, Lincoln-Liberty Building, Philadelphia, Pa.

NECROLOGY.

Mr. Morris Knowles, Pittsburgh, Pa.
Mr. Herman Dannenbaum, Philadelphia, Pa.
Dr. C. O. Mailloux, New York City.
Mr. Tinius Olsen, Philadelphia, Pa.
Mr. J. W. Ledoux, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

ALLCOCK, H. J., AND J. REGINALD JONES. The Nomogram. The Theory and Practical Construction of Computation Charts. 1932.

American Institute of Chemical Engineers. Transactions 1931, Volumes 26–27. 1931–1932.

American Type Founders Company. Specimen Book and Catalogue. 1923.

BABBITT, HAROLD E. Sewerage and Sewage Treatment. Fourth edition. 1932.

BALL, W. W. ROUSE. Mathematical Recreations and Essays. Tenth edition. 1928.

BEHAR, M. F. Fundamentals of Instrumentation. Part one of the Manual of Instrumentation. 1932.

BRAYMER, DANIEL H., AND A. C. ROE. Rewinding Small Motors. Second edition. 1932.

BRIDGMAN, P. W. Dimensional Analysis. 1931.

BUDGEN, N. F. The Heat-Treatment and Annealing of Aluminium and Its Alloys. 1932.

Chemical Catalog Company. Chemical Engineering Catalog. Seventeenth annual edition. 1932.

Chemists' Year Book. Edited by F. W. Atack. 1932.

CODDINGTON, HENRY. A System of Optics. Part 1. A Treatise on the Reflexion and Refraction of Light; Part 2, A Treatise on the Eye and Optical Instruments. 1829–1830.

DANA, EDWARD SALISBURY. A Text-book of Mineralogy, with an Extended Treatise on Crystallography and Physical Mineralogy. Fourth edition, revised and enlarged by William E. Ford. 1932.

DARROW, FLOYD L. Masters of Science and Invention. 1923.

EGGERT, JOHN. Physical Chemistry. Translated by S. J. Gregg. Translation of third edition of Lehrbuch der physikalischen Chemie, revised in collaboration with Dr. Lothar Hock. 1932.

Electrochemical Society. Transactions. Volume LXI. 1932.

FELDMAN, W. M. Rabbinical Mathematics and Astronomy. 1931.

GARARD, IRA D. An Introduction to Organic Chemistry. 1932.

GHEURY DE BRAY, M. E. J. Elementary Hyperbolics for Technical and Other Students. Specially Adapted to the Requirements of Beginners. In two volumes: Volume I, Hyperbolic Functions of Real and Unreal Angles; Volume II, The Applications of Hyperbolic Functions. 1931.

GILMORE, A. B. The Puerto Rico Sugar Manual, Including Data on Santo Domingo Mills. 1932.

GURWITSCH, LEO, AND HAROLD MOORE. The Scientific Principles of Petroleum Technology. New edition. 1932.

HARDING, LOUIS ALLEN. Steam Power Plant Engineering. 1932.

HAVEN, GEORGE B. Mechanical Fabrics. A Treatise upon Their Manufacture, Construction, Testing and Specification. 1932.

HEISENBERG, W. Les Principes Physiques de la Théorie des Quanta. Traduit de l'allemand par MM. B. Champion et E. Hochard. Préface de M. Louis de Broglie. 1932.

HOPKINS, ALBERT A. The Lure of the Lock. 1928.

HOPKINS, EDWARD S. Water Purification Control. 1932.

Hoyer-Kreuter Dictionnaire Technologique. Sixième édition, entièrement refondue par Alfred Schlomann. Tome 3, Français-Allemand-Anglais. 1932.

HUDSON, RALPH GORTON. Electronics. 1932.

Institution of Chemical Engineers. Transactions. Volume 9. 1931.

Jameson's Manufacturers' Practical Recipes. New and revised edition, complete in one volume. 1929.

JUDGE, ARTHUR W. The Testing of High Speed Internal Combustion Engines. With Special Reference to Automobile and Aircraft Types, and to the Testing of Automobiles. Second revised and enlarged edition. 1932.

Kaiser-Wilhelm-Institut für Kohlenforschung in Mulheim-Ruhr. Arbeiten. Gesammelte Abhandlungen zur Kenntnis der Kohle. Herausgegeben von Professor Dr. Franz Fischer. Zehnter Band (umfasst das Jahr 1930). 1932.

KELLS, LYMAN M. Elementary Differential Equations. First edition. 1932.

KNUDSEN, VERN O. Architectural Acoustics. 1932.

LEVINSON, HORACE C., AND ERNEST BLOOMFIELD ZEISLER. The law of Gravitation in Relativity. Second edition. 1931.

LIVERSEEGE, J. F. Adulteration and Analysis of Foods and Drugs. Birmingham Methods and Analyses of Samples. Review of British Prosecutions during Half a Century. 1932.

LOWE, BELLE. Experimental Cookery from the Chemical and Physical Standpoint. 1932.

MACELWANE, J. B., AND F. W. SOHON. Introduction to Theoretical Seismology. Part 2, Seismometry by F. W. Sohon. 1932.

MANLY, G. B. The Ford: V-Eight—'B' Four—'BB' Truck. 1932.

MARTIN, L. C. An Introduction to Applied Optics. Volume 1, General and Physiological; Volume 2, Theory and Construction of Instruments. 1930–1932.

MERRIMAN, MANSFIELD, AND HENRY S. JACOBY. A Text-Book on Roofs and Bridges. Part 2, Graphic Statics. Revised by Everett E. Ebling. Fifth edition, revised and rewritten. 1932.

MILNER, HENRY B. Sedimentary Petrography. With Special Reference to Petrographic Methods of Correlation of Strata and to Subsurface Oil Geology. Second revised and complete edition. 1929.

Mineral Industry: Its Statistics, Technology and Trade during 1931. Volume XL. 1932.

MOGENSEN, ALLAN H. Common Sense Applied to Motion and Time Study. First edition. 1932.

MOORS, C. JOHN. Aircraft Engine Mechanics Manual. 1932.

MOYER, JAMES A., AND RAYMOND U. FITTZ. Refrigeration. Including Air Conditioning and Cooling and Household Automatic Refrigerating Machines. Second edition. 1932.

National Research Council. Physics of the Earth. Volume V, Oceanography. 1932.

OLSEN, JOHN C. Unit Processes and Principles of Chemical Engineering. In collaboration with Crosby Field and others. 1932.

[Pliny (Caius Plinius Secundus) the Elder.] The Elder Pliny's Chapters on Chemical Subjects. Part II. Edited with translation and notes by Kenneth C. Bailey. 1932.

PRESCOTT, FREDERICK. Modern Chemistry. The Romance of Modern Chemical Discoveries. No date.

RICHARDSON, E. G. The Acoustics of Orchestral Instruments and of the Organ. 1929.

RIES, H., AND THOMAS L. WATSON. Engineering Geology. Fourth edition. 1931.

ROSSMAN, JOSEPH. The Law of Patents for Chemists. 1932.

SCHMIDT, JULIUS. A Text-Book of Organic Chemistry. English edition by H. Gordon Rule. Second edition, revised and extended. 1932.

SCHWAIGER, A. Theory of Dielectrics. Translated by Royal W. Sorensen. 1932.

SMYTHE, WILLIAM R., AND WALTER C. MICHELS. Advanced Electrical Measurements. 1932.

STEINMAN, D. B. The Wichert Truss. 1932.

TEJADA, J. DE D. A Spanish-English and English-Spanish Dictionary of Sugar House Terms. 1927.

TERMAN, FREDERICK EMMONS. Radio Engineering. First edition. 1932.

TURNEAURE, F. E., AND E. R. MAURER. Principles of Reinforced Concrete Construction. Fourth edition, revised and largely rewritten. 1932.

TURNER, L. B. Wireless. A Treatise on the Theory and Practice of High-Frequency Electric Signalling. 1931.

WEST, W. Acoustical Engineering. The Theory of Sound and Its Applications to Telephone and Architectural Engineering and to Acoustical Measurements and Research. A Text-book for Students and Engineers. 1932.

WIEN, W., AND F. HARMS, Editors. Handbuch der Experimentalphysik. Band 4, Hydro- und Aerodynamik; 4 Teil, Rohre, offene Gerinne, Zähigkeit. Herausgegeben von Ludwig Schiller. 1932.

WOODHOUSE, THOMAS. The Finishing of Jute and Linen Fabrics. 1928.

WORDEN, EDWARD CHAUNCEY. Chemical Patents Index. Volume 2, Index of Subjects C, D, and E. 1932.

BOOK REVIEWS.

BULLETIN OF THE NATIONAL RESEARCH COUNCIL, No. 85, June 1932, Physics of the Earth—V, Oceanography, 581 pages, tables, illustrations, 17 × 25.5 cms. Washington, National Academy of Sciences, 1932. Price $5.00.

There are several very imposing features about this bulletin. One looking for a pamphlet or misled by experiences with a newspaper largely filled with advertisements, will be disappointed. This bulletin of research has been compiled by a long list of students who have emerged into "experts" qualified to operate on the ocean.

Two oceanographers cover the bottom. G. W. Littlehales confines his attention to the configuration of the oceanic basins. Leon W. Collet takes up the deep sea deposits. It is amazing how interesting these remote regions can be made by those who can come back from the depths with trustworthy account of this unknown world. The power of Jules Verne still holds in our off hours but the marvels of the deep sea can compete with any serious person, interested in the earth on which we live or rather the earth that underlies the sea by the shores of which we have begun to live. The wealth of the ocean, or to be more specific, the potential resources in gold (which tails the list, page 114), silver, iodine, nitrate, magnesium, sodium and chlorine which are available in sea water should provoke some adventurous capitalist to reduce his surplus. Man has not begun to render the ocean as an abattoir renders a pig. The time may come, even in the near future, when man will grasp this inexhaustible resource.

Of a more geographic interest to that brave traveller who may elect to hike across the ocean floor are the depths of the several oceans and the ooze that pave

the way. The condition of track is all important to a sprinter. Of no less importance is the character of ooze to our submarine friend. He will quickly leave the sands and gravels of the continental shelves and then the scenery will be blue, red or green. Scenery is hardly the word to use in a world of abyssal night, at a temperature just below freezing, where the only thing to see is the floor. However, a very little thing can excite great minds. So, too, the minute, microscopic skeletons of the countless diatoms that infest the surface of the oceans shower their casts upon the floor of the sea. The Foraminiferæ together with silicates of alumina and oxides of iron produce blue ooze. Red muds exist where the oxides of iron predominate, while the abundance of glauconite grains and glauconitic casts are responsible for ocean floors of green color. Red-clay of various origins appears to be "the most characteristic and most widely distributed of all the deep-sea deposits. It occurs at the greater depths of the ocean remote from the land; hence it is one of the 'abyssal' sediments" (Collet, page 50).

Our adventurous voyageur may have a flare for metallurgic chemistry and the real object of his mission to these remote parts may be to determine the effect of the trace of arsenic on the life of a lobster, or the influence of copper during the young life of an oyster, or the importance of calcium as compared with strontium as building materials for the calcareous shells of marine organisms. If anyone undertakes such an errand he should take Physics of the Earth V with him. If the volume is too heavy, he should most certainly write on his sea-going cuff chapter five, by Thompson and Robinson, as it will provide the record of much that others have done in this salt-sea field.

Who can escape the rhythm of the surf as it breaks upon that temporary strand which we call the seashore? On top of the towering investments in the properties of innumerable watering places, beyond the riparian rights that might by the shifting of the shoulder of the true continent, extend to the edge of the shelf itself, on top of these matters of great moment to realtors, there are the pounding breakers. As Andrew Lang has put it:

> "And through the music of the languid hours
> They hear like Ocean on a western beach
> The surge and thunder of the Odyssey."

The mechanics of waves brings one down on the hard sand. Nevertheless, the description of the several kinds of waves as found in Chapter VI is well worth the reading by anyone who ever smells the salt. Patton and Harmer describe the movement of waves bringing a certain happy order out of the chaos of a choppy sea. The waves raised by the wind are far from haphazard eccentricities. They follow laws expressed in formulæ. For the relation of wave velocity to wind velocity:

$$v = 2.356\sqrt[3]{w^2},$$

in which v is the wave velocity and w the wind velocity. Or the general formula for velocities of waves in terms of length:

$$v = \sqrt{\frac{g}{2}\pi^1}.$$

"Approximately, therefore, the velocity of a wave is two and one-half times the square root of its length. A wave 400 feet in length therefore travels with a velocity of 45 feet per second or a little more than 30 miles an hour." An unsteady

passenger looking over the rail should find consolation in these observations on the open sea.

The waves of a swell have to be identified separately, as well as the calming effect on waves by wind, freezing, mud, seaweed and fish in school. The effect of oil is not so simple although in human terms more important. The wind apparently slides off the face of oily water, reducing waves technically to swells. Seismic waves that spank the bottoms of ships with such force as to convince the skipper that he has pounded a reef are, naturally, as rare as very special earthquakes. Probably the prettiest waves of all are those delicate short-lived waves that fringe the broken breaker as it licks the sand—waves of translation. The breaking of waves, on the old theory of friction against the shore, the tripping of a comber on the beach, is now replaced by Johnson's teaching:

"With constantly enlarging orbits and diminishing water supply, there must come a time when the volume of water is insufficient to build up the entire wave form, the deficiency manifesting itself as a 'hollowing' of the front of the wave. The water available endeavors to curve around through the entire orbit, but on reaching the top of the circle finds itself unsupported and collapses."

The tides and tidal movements are a great concern to any student of the subject and of very great concern to any pilot. To know the tides in a dangerous estuary is to keep a job. To disregard the tides in a strip of coastal water like Nantucket Sound where tide rips skip over bad shoals is to endanger the lives and property entrusted to the ship as well as losing a job (cf. Martha's Vineyard and the Nantucket, August 1932). I am not sure that the unlucky skippers of this collision could make full use of the exposition of tides and tidal currents as laid bare in chapter seven but they would develop a background which would make the foreground a little less painful. The measure of tides is relatively simple. The explanation of tidal action was hit upon by the genius of Sir Isaac Newton (Principia, 1687). Tides are caused not by the moon pulling the water of the sea away from the earth but rather due to the difference of attraction between water and land. The diurnal, semi-diurnal and long period forces all enjoy full description; for those of us who live near the Delaware River we can content ourselves with the formula:

$$R_d = 0.048vd \sin \phi,$$

in which R_d is the range difference in feet, v the velocity of the current in feet per second, d the distance between the banks of the waterway in statute miles, and ϕ the latitude.

The very practical value of the tides is very well known to any official charged with the care of harbors or rivers. The scouring action of the tides to relieve the mouths of rivers of sedimental bars, the effect of salt water in winter mixing with fresh water and producing a solution of lower freezing point has very great economic value to the harbor of St. John for example. Similarly oyster beds, Cape May salts, thrive where the tide sweeps in new salt water for the thirsty bivalves. More lofty is the consideration given to the lengthening of the day—"something like the thousandth part of a second in a century," due to the effect on the rotation of the earth by the friction of the tide. This prospect goes hand in hand with the retreat of the moon from the earth until that time "when day and month become equal, the lunar tide will cease completely, since the earth will no longer rotate relatively to the moon."

Equally chilling is the effect of ice in the sea, chapter ten written by Edward H. Smith. In addition to many historical references which seem hardly needed, as one might expect every explorer to the Arctic or Antarctic to observe on ice, there is phenomena of land ice and the tragically important fact of sea ice. Happily the International Ice Patrol have saved subsequent "Titanic" disasters.

Floyd M. Soule is singularly equipped to describe the instruments needed for measuring the sea as he used them with such good effect on the last cruise of the "Carnegie." A previous review has treated with this expedition. There should be word of appreciation of chapter eight in which George F. McEwen writes on the basic principles that underlie modern methods of dynamical oceanography. Such structure is necessary, I suppose, but to use a shore expression the wading is hip-high. Arnold Schumacher of the Deutsche Seewarte, Hamburg, Germany, similarly outlines, in chapter nine, oceanic circulation, the weaving of currents and findings of salinity, much useful information. In the fifteenth chapter A. G. Huntsman of the Biological Board of Canada traces life back to the sea, conjures land forms from the ocean and makes clear the effect of light, temperature, salinity and many other influences upon marinal life. Charles Schuchert of Yale University tells the story that always holds me spellbound, the old, old story of land-making, and mountain-making, cyclic inundation of the land and the grand theme of paleogeography.

H. W. ELKINTON.

CHEMICAL ENGINEERING CATALOG, 1932 (Seventeenth Annual) Edition, 847 pages, 21 x 28.5 cms. New York, The Chemical Catalog Company, Inc.

The writer has failed to provide himself with the volume for the year 1931, so will be unable to make a comparison showing wherein the more recent issue might differ. There is nothing left but to begin at the front and follow through.

First, the reader is informed that the Committee has been able to maintain the volume's size and comprehensiveness and this in spite of decreasing business with attendant curtailments in sales promotion, publicity and advertising budgets. The publishers offer a service:—If you want information as to names and addresses of manufacturers and sources of supply of chemical machinery, scientific apparatus, chemicals, raw materials and supplies, power plant equipment, ask them. Information as to the uses of various chemicals and materials, their prices, statistics of production exports and imports also may be secured.

As a time and trouble saver the first list is composed of firms whose products are catalogued within. Next, a Trade Name Index. The immense value of this is immediately apparent. There have been many instances when the "Trade Name" comprised all the meager information one had regarding a product. By means of this index the "trade name" is directly linked to the manufacturer.

Then, there is a Classified Index of Equipment and Supplies—another convenience and timesaver. Perhaps someone wishes to know where vacuum filters can be secured. Under this title will be found a list of twenty companies making them. This index covers all the conceivable equipment and supplies a chemical manufacturing concern might need.

The greater portion of the volume is occupied by the advertising and product listings of the various subscribing companies. There are about nine hundred of these and no doubt form a reputable and representative list of manufacturers. As

might be expected, new products and their companies appear in the new issue while at the same time old familiar ones have disappeared.

The Classified Index of Chemicals and Raw Materials seems very comprehensive in scope. A person may discover the one manufacturer of Methy-β-phenyl-α: β-dibromopropionate or sixty-five who sell acid sulfuric. The Chemical Manufacturers Index is especially interesting. Not only are the products of a company listed but the properties and uses or applications of each chemical are given. This provision should act to eliminate much preliminary correspondence between a prospective purchaser and the company.

The volume would not be complete without a "Technical and Scientific Books Section." In this section a very efficient system of classification is to be found. For publications on any particular subject just the authors' names are listed under the subject headings. The Subject Index is then followed by a section where approximately 2600 books are listed according to their authors.

A catalog of this type should be of considerable value to anyone concerned with the manufacture or utilization of chemical products. It is difficult to acquire a realization of its full value from a mere casual examination.

T. K. CLEVELAND.

COLLOID CHEMISTRY, THEORETICAL AND APPLIED. Collected and Edited by Jerome Alexander, Vol. III, second series on technological applications, 734 pages, illustrations, 15.5 x 23.5 cms. New York, The Chemical Catalog Co., Inc., 1931. Price $11.50.

This volume continues the symposium on the technical applications of colloid chemistry and again it is rich in information and suggestions. The four volumes have contained 202 papers by almost as many people representing 23 nations. This has insured a diversity of viewpoint with consequent breadth of vision.

M. Samec contributes an extremely interesting review of the colloid chemistry of cellulose itself with a list of 835 references. This serves as an introduction to the colloid chemistry of various carbohydrates and materials in which they are the principal constituents, including wood, paper, cellulose esters and smokeless powders, candy, sugar, and starches.

The theory of dyeing is discussed from three different viewpoints by Georgievics, Harrison, and Bancroft. The sizing and finishing of textiles receives brief treatment by Olney.

The ever fascinating properties of rubber and their changes under various treatments are covered in chapters by Spear and Dinsmore. The use of rubber latex as such has seen remarkable development in the past few years and has resulted in an even greater interest. An interesting thirty page summary of this is contributed by van Rossem. All of us have benefited by the work which has been done on compounding rubber and this adds interest to a chapter on the use of carbon black by Shepard.

Another discussion is on the theory of tanning; the participants are Procter, Stiasny, and McLaughlin. In view of the extreme complexity and variability of leather it is surprizing to find how much has been done to put the old art of tanning on a scientific basis. Gelatin derived from leather is an important raw material for photographic supplies so it is perhaps a more natural step to photography and photochemistry than appears at the first glance. Moquin's article on color

photography points out the ingenious methods used to produce pictures in natural colors. The chemistry of photography has been so carefully and extensively studied that relatively much more is known about it than about the general subject of photochemistry. Lüppo-Cramer and Sheppard respectively point out numerous connections with colloid chemistry.

The fact that casein can be dispersed in water with the aid of certain salts and alkalies and later brought into an insoluble condition leads to its use in adhesives, coatings, paints, plastics and insecticide sprays. Silk can be dispersed in a similar fashion and then again aggregated by proper treatment. The eventual commercial development of these reactions is predicted by von Weimarn.

The production and use of materials for forming surfaces which will protect and beautify materials is a study in colloidal systems. Paint, varnish, synthetic resins, water japans, and artificial mother-of-pearl are all given a place. A different type of surface is formed by the color lakes used where cloth does not dye readily. Still another colloidal method of protection lies in "the foam method of extinguishing fire."

"A knowledge of the colloid chemistry of bakery products such as bread, cake, cookies, doughnuts, etc., and of their ingredients, has helped to solve many perplexing problems." "Butter and margarine being solidified emulsions, and involving in their production the special treatment of milk (itself a complex colloid system), present many interesting problems in colloid chemistry and physics." Frey and Landis and Clayton thus furnish our bread and butter while the jelly is due to "the peculiarly interesting substance called pectin to which the extracts of certain fruits owe their jelly-forming properties." If you are not satisfied with milk, "in beer brewing the chemistry of interfaces is all important."

Besides, "cleansing processes are triply colloidal." "There is"—"a complex interplay of fabric colloids, soil colloids, and soap colloids in washing." "If soaps are typical colloids, so is dirty linen." Old and new detergents both receive their share of attention.

"Solidified" alcohol was first mainly considered as a fuel with some detergent uses. More recently it has been found more interesting in medicinal and toilet preparations.

Some colloidal aspects of water carried trade wastes and sewage are summarized by Buswell to complete this volume which is the last of the set. Chemists in general and colloid chemists in particular owe Jerome Alexander a debt of gratitude for undertaking the collection and editing of all the material in the four volumes. His extreme care is clearly illustrated by the negligible number of errors.

WM. STERICKER.

ACTUALITÉS SCIENTIFIQUES ET INDUSTRIELLES XXXI, Exposés de Physique Théorique publiés sous la direction de M. LOUIS DE BROGLIE, Professeur à la Sorbonne, Laureat du Prix Nobel. I, Sur une forme plus restrictive des Relations d'Incertitude d'après MM. Landau et Peierls. Par Louis de Broglie. Paris, Hermann et Cie, 1932. Price 6 francs.

The present pamphlet is the report of a critical analysis of a recent memoir by MM. Landau and Peierls which appeared in Zeitschrift fur Physik, Band 69, page 56 et seq. In this suggestive work which originates from the initiative of

Professor Bohr, the authors show that if the fundamental conceptions of relativity are introduced in the new mechanics, there follow relations of uncertainty which are more restricted than those of Heisenberg. These relations are applicable to electromagnetic magnitudes as well as to material magnitudes. This fact imposes some limits in the domain of validity of the methods usually applied in the new mechanics and should prove an important element in the theory of phenomena of which the nucleus is the seat.

L. E. P.

L'IDÉE GÉNÉRALE DE LA MÉCANIQUE ONDULATOIRE ET SES PREMIERES APPLICATIONS. Par Marcel Boll, 74 pages, 13 x 18 cms., paper. Paris, Hermann et Cie, 1932. Price 15 francs.

No one embarks upon a detailed study of analytical mechanics without a preliminary general training in the principles of that subject. Of the many excellent texts which have appeared designed for that purpose over many decades, their name is legion. With the advent of new conceptions on the transfer of energy in wave mechanics, leaders in the teaching of physical science are again confronted with the task of preparing the way for the prospective reader of the profound treatises of such famous investigators as de Broglie, Heisenberg, Schroedinger and Dirac. The task, alike for author and reader, is many-fold more difficult than with the classical mechanics where the simple rule of three goes far in the elucidation of first principles. The reader may be a bit disappointed that this outline of wave mechanics with applications to light emission, the electric current and the fundamentals of chemistry cannot be approached without a working knowledge of differential equations and vector analysis. Nevertheless the subject is brought much closer to the applications than will be found in the more complete but formal and abstract treatises. The work should prove most helpful in providing a background of actuality in the perusal of these treatises.

L. E. P.

LEÇONS DE CHIMIE ANALYTIQUE. Par Alcide Jouniaux, Professeur à la Faculté des Sciences de l'Université de Lille. viii–350 pages, 15 x 23 cms., paper. Paris, Librairie Scientifique Hermann et Cie., 1931. Price 60 francs.

In the processes of analytical chemistry we have one of the chief objectives of the theoretical methods and observed facts which comprise the substance of general chemistry. How best to present these processes, at once to harmonize with the general preparation which a student receives and to provide a practically useful text, is a problem which demands keen discrimination on the part of an author. Two courses are open. One is to follow the order set forth in general chemistry; the other, is to proceed according to the less rational but more practical plan of dwelling on method and technique, reliance being placed upon the student's prerequisite preparation for their proper coördination with general principles. The author endeavors to reconcile these two extremes of method. He lays stress on those technical details which a long experience in laboratory teaching has proved to be paramount, and throughout the text he insistently points out how the processes employed in analysis are always governed by a chemical principle.

The work is arranged in four major divisions: operations of gravimetric analysis; gravimetric dosage of anions and cations; quantitative analysis of organic

compounds; electrolytic analysis. The book is thorough and up-to-date in each of its divisions, it is provided with numerous bibliographic references to original sources, and is a model of orderly arrangement and typographical excellence. The subject-matter is based upon a part of the course of instruction conducted by the author at the University of Lille.

L. E. P.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 436, Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. II. Thick Wing-Various Radial-Engine Cowlings—Tractor Propeller, by Donald H. Wood, 42 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price ten cents.

This report is the second of a series giving the results obtained in the 20-foot wind tunnel of the National Advisory Committee for Aeronautics on the interference drag and propulsive efficiency of nacelle-propeller-wing combinations. The first report gave the results of the tests of an N.A.C.A. cowled air-cooled engine nacelle located in 21 positions with reference to a thick wing. The present report gives results of tests of a normal engine nacelle with several types of cowling and fairings in four of the positions with reference to the same wing.

Tests were made with no engine cowling, with a narrow variable-angle ring, two wide thin rings with different chord angles, and the hood previously used on the N.A.C.A. cowled nacelle.

Although the propulsive efficiency of the small uncowled nacelle is higher than that of the nacelle with any of the cowlings, the drag and interference are also higher, and the highest net efficiency is obtained with the N.A.C.A. cowled nacelle. Fairing the nacelle into the wing is an advantage when the cowled nacelles are located near the wing but is of little value when the nacelles are not cowled. Fairing the N.A.C.A. hood into the wing is detrimental. Side brackets on the nacelle when it is located ahead of the wing are to be avoided. The N.A.C.A. cowled nacelle located about 25 per cent of the chord ahead of the wing is the best tractor-nacelle arrangement. If the cowling is omitted with nacelle in this position, a loss of lift results, especially at high angles of attack. The proper location of nacelles and careful cowling are important in the high-speed range of flight, but in the lower speed ranges there is little advantage of one nacelle position or cowling over another.

Report No. 437, The Effect of Area and Aspect Ratio on the Yawing Moments of Rudders at Large Angles of Pitch on Three Fuselages, by Hugh L. Dryden and B. H. Monish, 12 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price five cents.

In view of the paucity of data on the effect of systematic changes in the vertical tail surfaces, measurements have been made of the yawing moments produced by rudder displacement for seven rudders mounted on each of three fuselages at angles of pitch of 0°, 8°, 12°, 20°, 30° and 40°. The dimensions of the rudders were selected to cover the range of areas and aspect ratios commonly used, while the ratios of rudder area to fin area and of rudder chord to fin chord were kept approximately constant.

An important result of the measurements is to show that increased aspect ratio gives increased yawing moments for a given area, provided the maximum rudder displacement does not exceed, say, 25°. If large rudder displacements are used, the effect of aspect ratio is not so great.

The work was conducted at the Bureau of Standards in coöperation with the Aeronautics Branch of the Department of Commerce and the National Advisory Committee for Aeronautics.

Report No. 438, Experiments on the Distribution of Fuel in Fuel Sprays, by Dana W. Lee, 17 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price ten cents.

The distribution of the fuel in sprays for compression-ignition engines was investigated by taking high-speed spark photographs of fuel sprays produced under a wide variety of conditions, and also by injecting them against pieces of Plasticine. A photographic study was made of sprays injected into evacuated chambers, into the atmosphere, into compressed air, and into transparent liquids. Pairs of identical sprays were injected counter to each other and their behavior analyzed. Small high-velocity air jets were directed normally to the axes of fuel sprays, with the result that the envelope of spray which usually obscures the core was blown aside, leaving the core exposed on one side.

The results showed that the distribution of the fuel within the sprays was very uneven. Under engine-operating conditions the fuel was subdivided into many small particles by the time it had penetrated 0.75 inch. In the cores of the sprays, these particles had a high velocity relative to the air in their immediate vicinity, but as their velocity was reduced, they were forced out of the core and formed the spray envelope. The shape of the central core varied with the density of the chamber air, becoming shorter and thicker with increasing air density.

Report No. 439, Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. V. Spoilers and Ailerons on Rectangular Wings, by Fred E. Weick and Joseph A. Shortal, 18 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price ten cents.

This report covers the fifth of a series of systematic investigations in which lateral control devices are compared with particular reference to their effectiveness at high angles of attack. The present report deals with tests of spoilers and ordinary ailerons on rectangular Clark Y wing models. In an effort to obtain satisfactory control throughout the entire angle-of-attack range that can be maintained in flight, various spoilers were tested in combination with two sizes of previously tested ordinary ailerons—one of average proportions and the other short and wide. In addition, one large spoiler was tested alone.

It was found that when ailerons and spoilers are used together the full effect of both is not obtained if the spoilers are located directly in front of the ailerons. With the proper combination of spoiler and aileron, however, it is possible to obtain satisfactory rolling control up to high angles of attack (15° to 20°), together with favorable yawing moments and small control forces. A moderate amount of rolling control with favorable yawing moments and small control forces was obtained with the large spoiler alone.

Report No. 441, A Flight Investigation of the Spinning of the NY-1 Airplane with Varied Mass Distribution and Other Modifications, and an Analysis Based on Wind-Tunnel Tests, by Nathan F. Scudder, 18 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price ten cents.

This report presents the results of an investigation of the spinning characteristics of the "NY-1" naval training biplane. The results of flight tests and an analysis based on wind-tunnel test data are given and compared. The primary purpose of the investigation was the determination in flight of the effect of changes in mass distribution along the longitudinal axis, without change of mass quantity or centroid.

The effect of varied mass distribution was to decrease the angle of attack and the linear and angular velocities, as ballast was moved from the center of gravity to the nose and tail of the airplane, without shift of centroid. Moderate changes in wing loading and dihedral of the wings and comparatively large changes in center-of-gravity position have small effects on the spin under the conditions of the tests. Different settings of ailerons and elevator altered the nature of the spin but did not bring about recovery, which was effected only by the rudder. The tests showed that full-down deflection of the elevator alone increased the rate of rotation, indicating that recoveries could best be made by using the rudder before moving the elevator down. Removal of a large portion of the fin and rudder covering (above the stabilizer and elevator) had no appreciable effect on the spin. A reasonable agreement was obtained between flight results and a numerical analysis, although the method of the analysis neglected many of the minor factors that usually are thought to influence the spin.

Report No. 444, Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. VI. Skewed Ailerons on Rectangular Wings, by Fred E. Weick and Thomas A. Harris, 13 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price five cents.

This report covers the sixth of a series of investigations in which various lateral control devices are compared with particular reference to their effectiveness at high angles of attack. The present report deals with flap-type ailerons hinged about axes having an angle with respect to the leading and trailing edges of the wing. Tests were made on four different skewed ailerons, including two different angles of skew and two sizes of ailerons. At the high angles of attack, all the skewed ailerons tested were slightly inferior with respect to rolling and yawing moments to straight ailerons having the same span and average chord. Computations indicate that the skewed ailerons are also inferior with respect to hinge moments.

A STUDY OF THE INDUCTION MOTOR, by F. T. Chapman, D.Sc. (Eng.) Lond., M.I.E.E., Assoc. M. Inst. C. E. xvi–289 pages, plates, tables, diagrams, 15 × 23 cms., cloth. New York, John Wiley & Sons, Inc., 1930. Price $5.50.

As compared with other branches of electrical engineering industry, the development and refinement of the induction motor adapted to the multiplicity of uses

to which it is now applied is an advance which has been stimulated by the now widespread adoption of alternating current networks for power distribution. In the early days of electric power industry such noted engineers as Sylvanus P. Thompson, Behrend, Steinmetz and others, devised practical and sound methods for the analysis of this type of alternating current motor. Upon that secure foundation, the author has extended the many component elements of rational design.

"The scope of the book is restricted to machines without commutators in order to keep it within convenient dimensions, and no reference is made to the difficult problems of heating or to the interesting history for the same reason. The rotating field theory has been adopted because I think it elucidates more easily than others some of the more important secondary phenomena of the motor. The argument has been developed by means of simple algebra and geometry only, but it can be converted into terms of vector algebra quite readily by those who prefer this medium. I have purposely avoided the introduction of the 'equivalent network' since I consider that, although this device is sometimes useful as a mnemonic, it may distract attention from the phenomena occurring in the real motor." The book is a model of condensation, no words are wasted, yet the explanations are adequate and the diagrams and algebraic deductions most generous in quantity and clarity. The volume of the work might have been reduced by the use of thinner paper and in a future edition it is hoped the author may include some historical notes and bibliographical references.

L. E. P.

NATIONAL RESEARCH COUNCIL, TRANSACTIONS OF THE AMERICAN GEOPHYSICAL UNION, Thirteenth Annual Meeting, April 28 and 29, 1932, Washington, D. C. 401 pages, maps, tables, illustrations, 17 × 24.5 cms. Washington, National Research Council, 1932.

This compendium of the varied and useful informations of the geophysical section of the National Academy of Sciences brings one up to date on geodesy, seismology, meteorology, terrestrial magnetism and electricity, oceanography, volcanology and hydrology. Reports and papers indicate the embracive activities of this section of the Society on the sea, in the air and on dry land.

By the happy process of photostat printing the typewritten manuscripts are reproduced in a way that makes them easily read as well as a matter of lesser expense. Those interested in the ocean floor will find this binder of reports most informative.

H. W. ELKINTON.

COMBUSTION: A REFERENCE BOOK ON THEORY AND PRACTICE. Third Edition. 208 pages, 114 tables, 58 charts and 60 figures. New York American Gas Association, 1932.

The principal objective of this publication is to place a tool in the hands of the industrial gas engineer with which to work out problems relating to the phenomena of combustion. According to the "Preface" the intent of the book is not to claim for gas an undisputed superiority for every heating process but to show the steps whereby efficient and economical installations can be engineered. It is pointed out that the price paid per fuel B.t.u. is not the whole story nor do such figures

necessarily indicate that the overall heating costs shall be higher. Other factors, such as heating efficiency, equipment cost, labor expense, time saving and obsolescence rates, must be taken into consideration.

Every engineer, some time or other, has had occasion to make combustion studies or calculations involving B.t.u. efficiencies, heat transfer or even heat balances. Such data have not been obtained easily. A portion will be in one handbook, the remainder in some other place difficult to locate. Moreover, in all probability a portion of the data and some of the equations will be expressed in the wrong system of units and must be converted laboriously. As might be expected a large portion of the book is devoted to the presentation of engineering data. Such basic information applies not only to the fuels themselves but also to the materials and equipment serving as receptors of the heat evolved.

The book divides roughly into two parts, theoretical and practical. The more advanced theories on the chemistry of combustion, heat transfer and the design of atmospheric burners have been included. The chapter on thermal capacity should prove almost indispensable. It contains tables for the specific heats of well known solids, liquids and gases as well as their latent heats of fusion and of evaporation.

Of all the calculations incident to heating problems that of heat transfer appears to involve the most elaborate and complicated equations. Chapter five has been devoted to an extensive series of workable formulas for calculating heat transfer under various conditions. The data and equations have been critically selected and are based upon the film concept of heat transference.

The chapter on combustion data of commercial gases should prove of great practical value. It includes tables giving the limits of inflammability and ignition temperatures for both simple and commercial gases. The charts showing the relation between the CO_2 content of flue gases and their heat contents should be particularly worth while.

Following a very complete treatise on atmospheric burners is a very helpful chapter on industrial combustion equipment. Directions are furnished on how to set about the laying out of gas furnaces of the simpler types. A portion of the chapter deals with the characteristics of various types of industrial burners and mixers. A discussion of temperature control includes descriptions of the several types of temperature measuring and controlling apparatus. Many practical suggestions are to be found in the chapter on heat salvage methods. These involve preheating, recirculation, recuperation, regeneration and waste heat boilers.

The subject of gas analysis has not been neglected. Careful directions are given for correct sampling, preparation of the analytical reagents and manipulation of both the Orsat and Elliot apparatus. The detection of small amounts of carbon monoxide also is described.

The final chapter deals with fuel comparisons and is frankly written to provide the gas industry with an outline of the principal selling arguments showing why gas is such an advantageous fuel. The high points in this chapter are the charts showing at what costs gas may successfully compete with coal, oil or electricity. Thus for domestic cooking 15 cu. ft. of manufactured gas are equivalent to one kilowatt-hour of electricity. If a householder is paying on an average of $1.20 per 1000 cu. ft. of gas he must receive his electricity at 1.8 cents per kilowatt-

hour in order to operate the cook-stove as economically. Similar data are given for comparing house heating by gas and by oil.

The book has an Appendix "A" that discusses the calculation of reaction constants. Appendix "B" contains a table of correction factors for temperature and pressure and several convenient tables of conversion factors.

T. K. CLEVELAND.

PUBLICATIONS RECEIVED.

The Catalytic Oxidation of Organic Compounds in the Vapor Phase, by L. F. Marek and Dorothy A. Hahn, American Chemical Society Monograph Series, 486 pages, illustrations, 16 × 23.5 cms. New York, The Chemical Catalog Company, Inc., 1932.

A Demonstration Visual Test, by M. Luckiesh and Frank K. Moss, 9 pages, plates, illustrations, 15 × 23.5 cms. Cleveland, General Electric Company.

La Theorie Atomique et la Description des Phenomenes, Quatre articles precedes d'une Introduction, par Niels Bohr, Traduction Francaise de Andree Legros et Leon Rosenfeld, 111 pages, 14.5 × 23.5 cms. Paris, Gauthier-Villars et Cie, 1932.

National Advisory Committee for Aeronautics, Technical Notes: No. 433, The Pressure Distribution over a Standard and a Modified Navy Elliptical Wing Tip on a Biplane in Flight, by Richard V. Rhode, Langley Memorial Aeronautical Laboratory, 29 pages, tables, diagrams, 20 × 26 cms. Washington, Committee, 1932. No. 434, Influence of Several Factors in Ignition Lag in a Compression-Ignition Engine, by Harold C. Gerrish and Fred Voss, Langley Memorial Aeronautical Laboratory, 8 pages, diagrams, 20 × 26 cms. Washington, Committee, 1932.

CURRENT TOPICS.

Pneumonia and Drugs.—(United States Department of Agriculture, Clip Sheet No. 746.) According to DR. F. J. CULLEN of the Federal Food and Drug Administration there is no magic ointment inhalant or other medical preparation that can be relied upon to cure pneumonia, diphtheria, tuberculosis or sinus infections. Approximately one year ago a Federal court ordered destroyed a shipment of a "cure-all" labeled as having remedial value for pneumonia, congested lungs, sores, ulcers, coughs, asthma, sore throat and numerous related diseases. Analysis of a sample of the article showed it to consist essentially of petrolatum mixed with about 6 per cent. of oil.

C.

Chlorination of Swimming Pool Water.—At times, the statement is made that, after chlorination, the microörganisms remain viable, but their growth is inhibited by the free chlorine which is present in the water and accompanies them into the culture media. DAVID WILBUR HORN (*Hahnemannian Monthly*, 1932, lxvii, 776–780, *Am. J. Pharm.*, 1932, **104**, 651) has made certain analytical determinations on normally chlorinated swimming pool waters containing between 0.2 and 0.6 parts free chlorine per million, and on the same waters after addition of 1.4 milligrams of sodium thiosulphate pentahydrate per 100 cc. of sample as an antichlor; this treatment sufficed to prevent any color reaction with orthotolidine. The use of the antichlor had no appreciable effect upon the hydrogen ion concentration (pH), the bacterial count, and the presumptive test for the presence of microörganisms of the colon group. Therefore, the results obtained on the bacteriological examination of water are not likely to be misleading on account of the presence of traces of free chlorine.

Within the conditions covered by the experiments, a swimming pool water may be judged safely by bacteriological results obtained by the usual procedure.

J. S. H.

Citric Acid in Milk.—B. G. HARTMANN AND F. HILLIG (*Jour. Asso. Off. Agric. Chem.*, 1932, XV, 643–645) examined five samples of market milk, and found the citric acid content to be between 0.163 and 0.177 gram per 100 cc. A sample of dry whole milk contained

1.32 per cent. of citric acid; this corresponded to 0.173 per cent. of citric acid in the reconstituted milk.

J. S. H.

Chemical Gardens.—C. C. PINES (*Am. J. Pharm.*, 1932, CIV, 665–666) describes the plant-like structures obtained by introduction of a crystal of a soluble salt of certain metals into a solution obtained by mixing 1 volume of sodium silicate (water glass, specific gravity approximately 1.4) with 3 or 4 volumes of distilled water. The color of the structure varies with the cation, being white with lead, magnesium, zinc, and aluminium, bright yellow with uranyl, green with nickel, purplish blue with cobalt, greenish blue with bivalent copper, reddish brown with ferric iron, white changing to green with ferrous iron, and white changing to light brown with bivalent manganese.

J. S. H.

Quinine Hydrobromide with Trihalogenmethane of Crystallization.—W. SCHNELLBACH AND JOSEPH ROSIN (*J. Am. Pharm. Asso.* 1932, XXI, 1009–1012) have obtained two crystalline compounds of quinine hydrobromide; the one contains two and one-half molecules of chloroform of crystallization, the other two molecules of bromoform of crystallization.

J. S. H.

Carbon Monoxide Content of Gas.—MAX TRUMPER (*Int. Clinics*, 1932, [42] iii, 221–225) states that natural gas contains no carbon monoxide while manufactured gas may contain from 20 to 30 percent. or even more, carbon monoxide. The lethal dose of carbon monoxide may be less than 1 gram; inhalation of air containing 0.4 per cent. carbon monoxide for 1 hour may produce death. Addition of natural gas to manufactured gas decreases the carbon monoxide content, lessens the toxicity, and increases the heating or fuel value per cubic foot.

J. S. H.

Chlorine Disinfectants.—A. C. FAY (Agric. Exp. Station, Kansas State Coll. Agric. and App. Science, Circular 160, 1–8, 1931) describes the preparation and use of solutions of calcium hypochlorite and sodium hypochlorite for disinfection in the dairy industry. The disinfectant solution pumped through pipelines, vats, etc. should still contain at least 50 parts per million of available chlorine as it leaves the last piece of apparatus. The available chlorine (parts per million) content of the solution used for sub-

merging well-cleaned bottles, pails, separator parts, etc. should be at least 50 when the time of action exceeds 1 minute, and at least 100 when the period is less than 1 minute. When applied as a spray, the solution should contain at least 200 parts per million of available chlorine. The solution must be clear, and should be used cold.

J. S. H.

Use of Collodion Sacks for the Crystallization of Organic Compounds.—HENRY TAUBER AND ISRAEL S. KLEINER (*Jour. Chem. Ed.*, 1932, IX, 1970–1972) recommend the use of collodion sacks for the crystallization of organic compounds which have relatively high molecular weights and ordinarily do not dialyze. When a concentrated solution of such a compound (e.g. 20 per cent. maltose, 10 per cent. sucrose, 10 per cent. lactose, 10 per cent. tartaric acid, 1 per cent. cystine hydrochloride in 3 per cent. hydrochloric acid) is placed in a collodion sack, the open end is tightly closed, and the sack is suspended in the air, then crystals of these organic compounds deposit within the bag. Crystallization is comparatively rapid. Many inorganic salts diffuse through the wall of the sack and crystallize on its outer surface.

J. S. H.

Plastics.—(*Chem. & Ind.*, *51*, 868, 1932). Just recently, the Society of Chemical Industry welcomed as a new integral part, a Plastics Group. This is a sign of times. Ordinarily we look upon "Plastics" as synthetic organic compounds which, under the influence of heat and pressure, become plastic and moldable into desired forms and shapes. Very often such treatment produces a setting-up action within the plastic material and it becomes rigid and permanently non-plastic under all subsequent conditions. Chronologically, clay probably is the oldest known plastic material. Rubber is well known and so extensively applied it can be considered as in a field by itself.

H. V. PATTER, the author of this paper, has limited himself to a discussion of the synthetic organic plastic substances. Celluloid, probably the best known of all, is prepared by first treating cellulose with a mixture of strong nitric and sulfuric acids. This treatment produces a nitrocellulose which when plasticised with camphor gives "Celluloid." This is insoluble in water and becomes plastic at about the temperature of boiling water whereupon it may readily be molded into shapes that retain their contour when cooled. Celluloid was first prepared commercially in 1869 and is still the most important cellulose derivative from a commercial point of view.

We all are familiar with celluloid brushes, combs, battery cases, ping-pong balls, unbreakable watch crystals, dolls, toys and safety glass.

Another important cellulose derivative is that of cellulose acetate. Cotton linters are treated with a mixture of acetic acid and its anhydride along with a condensing agent to bring about removal of water. This is done under rigid temperature control. Cellulose acetate possesses the advantage of forming inflammable transparent films. These films are also waterproof and make particularly appropiate wrappers for food products. Unlike celluloid, an unbreakable glass of the acetate derivative is stable toward light and relatively transparent to ultraviolet radiation. Cellulose acetate is an important constituent of waterproofing lacquers particularly suitable for coating airplane wings.

One of the most remarkable plastics of all time is Casein. The chief constituent of cheese and high in food value has been made to yield brightly colored permanent objects of widespread utility. The secret of casein's metamorphosis into a plastic lies in its treatment with formaldehyde, a well known fumigator and disinfectant. Such treatment renders the casein tough and insoluble. The dry process of manufacture is now generally employed and consists in combining carefully prepared powdered casein, fillers, colors and some water in a mixing machine. The resulting damp powder will adhere under pressure and may be extruded from dies in the shape of rods, tubes, sheets, etc. After hardening in a formaldehyde bath the material may be turned, drilled or stamped into various desired forms.

In the field of natural resin plastics shellac probably is the outstanding member. It is a most important constituent of disc gramophone records. In fact, the record making industry has consumed more than half the total world production of shellac in recent years. Shellac has been eminently suitable as the binding material for records since it exhibits a resiliency that makes it relatively immune from wear and tear of a needle.

Synthetic resins may be looked upon as the "stone rejected by the builders and now become the head of the corner." Almost all organic chemical reactions produce a certain amount of resinous "mess." To the research chemist these condensation products were a nuisance and something to get rid of as quickly as possible. Thus, the reactions that produce the present-day commercial resins were known many years ago but it was not until about 1908 that the first of these, a phenolformaldehyde condensation product was produced by Dr. Baekeland in the form which permitted commercial handling. The preparation of this product consists in placing the

phenol or phenols in a digester with formaldehyde and an alkali or acid catalyst added depending on whether a thermo-setting or non-thermo-setting resin is desired. Details of the operations are looked upon as a trade secret.

Another class of resins can be formed from urea or thiourea and the products are generally marketed in the form of "moulding powders." These powders are the basic raw material for a new and growing moulding industry. Mixed with fillers, the chief of which is woodmeal, these powders can be heated to about 375° F. whereupon they change from the fusible state to the hard infusible form in 1 to 3 minutes.

A newer type of synthetic resin is prepared by heating together glycerol and phthallic acid in a closed digester under close temperature control until a clear water-white syrup or resin is formed on cooling. This resin, cast in various shapes and forms, is allowed to age or undergo a hardening out process.

Coumarone resins are produced from a mixture of polymerizable substances found in a certain distillation fraction of coal tar. These substances chiefly consist of coumarone, indene and styrol and can be transformed into resins very simply by contact with concentrated acid. These resins are readily soluble in benzene and similar solvents and are extensively used in varnishes. It is understood that chewing gum may contain 7 to 10% of such resins.

Benzyl cellulose is a thermo-plastic but not a thermo-setting plastic. It can be heated up to 180° C. without decomposition, is relatively noninflammable and has very good water resistance, being of the order of 0.1% after 24 hours immersion in water.

While the plastic industry is yet relatively small compared to other industries such as the steel or textile, its possibilities appear limitless and application for these products are only in their infancy. Up to the present plastics have in many cases been adapted to meet existing conditions where they could; in the future, designs and construction will conform to the characteristics of the plastics themselves.

C.

Fake Medicines.—(U. S. Department of Agriculture Clip Sheet No. 749.) Medical fakers and quacks have a habit, amusing, were it not so misleading, of dubbing their nostrums with flowery and high-sounding names. Numerous patent medicines seized by the Government were found to bear such names as "bear oil," "life wine," "magic trokeys," "life balm" and the like. In one instance several dozen bottles of a medicine labeled "Walker's Old Indian Health Tonic" were confiscated and destroyed. This preparation

was described as the unfailing remedy for laziness and a drowsy, tired, sleepy feeling. For indigestion, dizziness, sick headache, numbness, or chills, kidney or bladder troubles, weakness, stimulates and purifies the blood." The so-called remedy was found to consist of small amounts of magnesium sulfate (Epsom salts), iron chloride, quinine sulfate and water. At least such a mixture should make the taker feel different.

While we are on the subject, mention should be made of the case where a product composed of the ground, sterile branches of Field Horsetail (Equisetum arvense) was labeled as a relief for diabetes and anemia. This so-called "photo-synthetic tea" is supposed to exert its curative action by making the sugar normal and the blood red.

C.

THE FRANKLIN INSTITUTE

OFFICERS FOR 1932

President	NATHAN HAYWARD
Vice-presidents	HENRY HOWSON C. C. TUTWILER WALTON FORSTALL W. CHATTIN WETHERILL
Secretary	HOWARD MCCLENAHAN
Assistant Secretary and Librarian	ALFRED RIGLING
Treasurer	BENJAMIN FRANKLIN
Assistant Treasurer	MARSHALL S. MORGAN
Controller	WILLIAM F. JACKSON, JR.

Board of Managers

HENRY BUTLER ALLEN
GEORGE H. BENZON, JR.
EDWARD G. BUDD
FRANCIS T. CHAMBERS
G. H. CLAMER
WALTON CLARK
CYRUS H. K. CURTIS
CHARLES H. EWING
SAMUEL S. FELS
ARTHUR W. GOODSPEED
CLARENCE A. HALL
GEORGE A. HOADLEY
A. ATWATER KENT
L. H. KINNARD
ELISHA LEE
ROBERT W. LESLEY
LIONEL F. LEVY
HORACE P. LIVERSIDGE
MALCOLM LLOYD, JR.
CHARLES PENROSE
GEORGE WHARTON PEPPER
JAMES S. ROGERS
GEORGE D. ROSENGARTEN
HASELTINE SMITH

INDEX TO VOL. 214.

Absorption in electric condensers (Maddison), 327
Allen, Mildred: Experimental work on the transmission of electrons by thin gold films, 43
Allen, Mildred: Transmission of electrons by thin films; an historical résumé, 25
Astronomers and their telescopes (Swasey), 265
Atmosphere. Ionization of the (Koller), 543
Bender, William: Physics and the method of coincidences, 443
Book Reviews:
Alexander, J.: Colloid chemistry, vol. 3, 762
Allen's commercial organic analysis, vol. ix, ed. 5, 368
Appleton, E. V.: Thermionic vacuum tubes and their applications, 122
Baker, E. A.: Caving, 126
Bangay, R. D.: The elementary principles of wireless telegraphy and telephony, 121
Boll, M.: Exposé électronique des lois de l'électricité, 613
Boll, M.: L'idée générale de la mecanique ondulatoire, 764
Broglie, L. de: Actualities scientifiques, 31, 763
Broglie, L. de: Introduction a l'étude de la mécanique ondulatoire, 493
Broglie, L. de: Receuil d'exposés sur les ondes et corpuscules, 372
Broglie, L. de: La theorie de la quantification dans la nouvelle mécanique, 494
Chapman, F. T.: A study of the nduction motor, 767
Chemical Engineering Catalog, 1932, 761
Chemical patents index, vol. 2, 616
Coker, E. G. & L. N. G. Filon: A treatise on photo-elasticity, 370
Combustion. A reference book, ed. 3, 768
Curie, I. & F. Joliot: L'existence du neutron, 614
Curtis, Harry A.: Fixed nitrogen, 494
Eastman Kodak Company: How to make good pictures, 497
Fleury, P.: Étalons photometriques, tome II, 491
Hadfield, R. A.: Faraday and his metallurgical researches, 620
Heisenberg, W.: Les principes de la théorie des quanta, 614
Jones, S. Bayne-: Man and microbes, 369
Jouniaux, A.: Lecons de chimie analytique, 764
Koshkin, S. J.: modern materials handling, 492
Loeb, L. B.: The nature of a gas, 124
Macelwane, J. B. & F. W. Sohon: Introduction to theoretical seismology, part II, 615
Malisoff, W. M.: Meet the Sciences, 249
Mason, W. P.: Examination of water, ed. 6, 248
Melluish, R. K.: An introduction to the mathematics of map projections, 122
Menge, E. J. vK.: Jobs for the college graduate in science, 368
Nassau, J. J.: A text-book of practical astronomy, 615

National Research Council, Transactions of the American Geophysical Union, 768
National Advisory Committee for Aeronautics, Report: No. 415, 124; No. 416, 125; No. 417, 125; No. 419, 126; No. 420, 372; No. 421, 496; No. 422, 251; No. 423, 251; No. 424, 496; No. 425, 373; No. 426, 373; No. 427, 497; No. 428, 497; No. 429, 617; No. 430, 617; No. 431, 618; No. 432, 618; No. 433, 619; No. 434, 619; No. 435, 620; No. 436, 765; No. 437, 765; No. 438, 766; No. 439, 766; No. 440, 620; No. 441, 767; No. 444, 767
National Research Council, Bulletin No. 85, 758
Newman, F. H.: Recent advances in physics, 247
Paul, J. H.: The last cruise of the Carnegie, 123
Revue d'Acoustique No. 1, 250
Sarton, G.: Introduction to the history of sciene, vol. II, 119
Tautz, H. E. & C. J. Fruits: The modern motor-driven woodworking shop, 121
Buc, H. E.: The red shift, 197
Circuit interrupters. Electric arc in (Slepian), 413
Coincidences. Method of, Physics and the (Bender), 443
Colwell, Robert Cameron: The vibrations of rods and plates, 199
Condon, E. U.: Quantum phenomena in the biological effects of radiant energy, 105
Cope, Thomas D.: The Rittenhouse diffraction grating, 99
Cosmic rays (Johnson) 665
Current Topics: 24, 42, 116, 129, 154, 166, 214, 222, 254, 264, 274, 326, 344, 366, 375, 464, 472, 488, 501, 624, 690, 708, 734, 771
Detonators, electric. Photography of disturbance sent out by the explosion of (Gawthrop) 647
Diffraction grating. Rittenhouse (Cope), 99
Earth's magnetic field. Orbits of electrons in (Swann), 465
Eclipse expedition of the Franklin Institute (Stokley), 735
Eisenhour, B. E. & F. G. Tyzzer: Elastic properties of various materials and their effect on the transmission of vibrations, 691
Elastic properties of various materials (Eisenhour & Tyzzer), 691
Electric arc in circuit interrupters (Slepian), 413
Electric condensers. Absorption in (Maddison), 327
Electron attachment (Zeleny), 513
Electron diffusion, (Zeleny), 513
Electron excitation function for the sharp series of orthohelium (Maxwell), 533
Electron orbit in the magnetic equatorial plane of the earth (Swann), 465
Electrons, Transmission of, by thin films (Allen), 25
Electrons, Transmission of, by thin gold films, 43
Elon and hydroquinone. Most economical concentrations for motion picture film (Gundelfinger), 223
Ether. Evidence for the constitution of (Mackaye), 73
Fitch, A. L.: The magnetic field intensity near a circular loop carrying an electric current, 215
Fitzgerald, Alan S.: A direct current bushing transformer, 709
Franklin Institute
Bartol Research Foundation.
Communication No. 66: Transmission of electrons by thin films; an historical résumé (Allen), 25
Communication No. 67: Experimental work on the transmis-

sion of electrons by thin gold films (Allen), 43
Communication No. 68: The use of a thermionic tetrode for voltage control, 155
Communication No. 69: An electron orbit in the magnetic equatorial plane of the earth (Swann), 465
Notes: 481, 597
Library Notes: 118, 247, 367, 490, 612, 755
Medal day meeting, 345
Membership Notes: 117, 489, 611, 754
Science and the Arts Committee, Abstract of proceedings: June 8, 1932, 117; October 5, 1932, 610; November 9, 1932, 754
Stated meeting, proceedings: October 19, 1932, 609; November 16, 1932, 753
Franklin Institute eclipse expedition (Stokley), 735
Gawthrop, D. B.: Propagation tests and the photography of the disturbance sent out by the explosion of commercial electric detonators, 647
Generators, Engine-driven, Stone, 633
Gundelfinger, Alan M.: A method for the calculation of the correct and most economical concentrations of elon and hydroquinone in a borax developer for motion picture film, 223
Gyroscope. Elementary theory of the (Tea), 299
Hanawalt, J. D.: Fine structure in x-ray absorption spectra, 569
Harvey, E. Newton: The microscope-centrifuge and some of its applications, 1
Hydroquinone. Most economical concentrations for motion picture film (Gundelfinger), 223
Ionization of the atmosphere (Koller), 543
Ions. Negative, Aging of, in commercial nitrogen (Zeleny), 513
Ives, Frederic E.: Polychrome photography, 163
Johnson, Thomas H.: Cosmic rays—theory and experimentation, 665
Johnson, Thomas H. & J. C. Street: The use of a thermionic tetrode for voltage control, 155
Koller, Lewis R.: Ionization of the atmosphere and its biological effects, 543
Lenard, Philipp: Some scientific views, 257
Mackaye, James: Evidence for the constitution of the ether, 73
Maddison, R. E. W.: Absorption in electric condensers, 327
Magnetic field intensity near a circular loop carrying an electric current (Fitch), 215
Materials. Elastic, properties of (Eisenhour & Tyzzer), 691
Maxwell, Louis R.: The absorption of radiation originating from a beam of electrons in helium: a note on the electron excitation function for the sharp series of orthohelium, 533
Microscope-centrifuge (Harvey), 1
Motion pictures. Talking, Development and use of (Wilcox), 137
Nitrogen. Commercial, Electron diffusion, electron attachment, and the aging of negative ions (Zeleny), 513
Ocean. Resources of the (Taylor), 167
Oscillations. Non-unilateral (Stone) 633
Photography. Polychrome (Ives), 163
Physics and the method of coincidences (Bender), 443
Plates. Vibrations of rods and (Colwell), 199
Polychrome photography (Ives), 163
Portland, Oregon. St. Johns bridge, Design and construction (Steinman), 377

Publications Received, 128, 252, 373, 498, 622, 770
Quantum phenomena in the biological effects of radiant energy (Condon), 105
Radiant energy. Quantum phenomena in the biological effects of (Condon), 105
Radiation. Absorption of, from a beam of electrons in helium (Maxwell), 533
Red shift (Buc), 197
Resources of the ocean (Taylor), 167
Rittenhouse diffraction grating (Cope), 99
Rods. The vibrations of (Colwell), 199
St. Johns bridge, Portland, Oregon. Design and construction (Steinman), 377
Scientific views (Lenard), 257
Slepian, Joseph: The electric arc in circuit interrupters, 413
Steinman, D. B.: The design and construction of the St. Johns bridge at Portland, Oregon, 377
Stokley, James: The Franklin Institute eclipse expedition 735
Stone, M.: Non-unilateral oscillations. Governor-controlled engine-driven generators (Stone), 633
Street, J. C. & Thomas H. Johnson: The use of a thermionic tetrode for voltage control, 155
Swann, W. F. G.: An electron orbit in the magnetic equatorial plane of the earth, 465
Swasey, Ambrose Astronomers and their telescopes, 265
Talking moving pictures. Development and use of (Wilcox), 137
Taylor, Harden F.: Resources of the ocean, 167
Tea, Peter L.: Elementary theory of the gyroscope, 299
Tetrode, thermionic, for voltage control (Street & Johnson), 155
Transformer. A direct current bushing (Fitzgerald) 709
Tyzzer, F. G. & B. E. Eisenhour: Elastic properties of various materials and their effect on the transmission of vibrations, 691
U. S. Bureau of Standards, Notes: 107, 237, 357, 473, 585, 747
Vibration of rods and plates (Colwell), 199
Vibrations. Elastic properties of materials and their effect on (Eisenhour & Tyzzer), 691
Voltage control. Thermionic tetrode for (Street & Johnson), 155
Wilcox, H. M.: Development and use of talking motion pictures, 137
X-ray absorption spectra. Fine structure in (Hanawalt), 569
Zeleny, John: Electron diffusion, electron attachment, and the aging of negative ions in commercial nitrogen at atmospheric pressure, 513

PERIODICAL ROOM
GENERAL LIBRARY
UNIV. OF MICH.

Journal
of
The Franklin Institute

DECEMBER, 1932

1826 1932

Published Monthly by
THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA
LANCASTER, PA. PHILADELPHIA, PA.